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CHARLES AUGUSTUS YOUNG

By EDWIN B. FROST

Charles Augustus Young was born on December 15, 1834, at Hanover, New Hampshire, the seat of Dartmouth College. His father, Ira Young, had in the previous year begun his duties as professor of mathematics and natural philosophy in the college, in succession to his father-in-law, Ebenezer Adams, who had occupied the same chair from 1810 to 1833. Ira Young had married Eliza M. Adams, daughter of Ebenezer Adams, and Charles Augustus was their first child. The Young and Adams families were both of English origin but had lived in New Hampshire for several generations. Ira Young's professorial chair was changed to that of natural philosophy and astronomy in 1838, and was filled by him with distinguished success until his death twenty years later.

An interest in science was thus natural to Charles Young, both by association and by inheritance. Endowed with an unusually active mind, he was ready for college at the age of fourteen and a half years—very early even for those times. Four years later, in the summer of 1853, he received the degree of Bachelor of Arts, the intellectual leader of his class of about fifty men. From early youth he had been accustomed to assist his father, when possible, in his scientific duties, and his skill in manipulation of instruments was no doubt partly due to this early experience. It was thus natural for

NOTE.—The accompanying portrait was taken at Princeton in April 1897, when Professor Young was 62 years old.

Ira Young to take his son with him when he made a trip to Europe in 1853, in quest for instruments for the Shattuck Observatory, then in process of establishment at the college.

For two years after graduation Charles Young taught the classics in the well-known preparatory school, Phillips Academy, at Andover, Massachusetts. During the next year he studied in the theological seminary at Andover, in accordance with an early plan to become a missionary, continuing for a part of the year his instruction at the academy.

An invitation to become professor of mathematics, natural philosophy, and astronomy at the Western Reserve College at Hudson, Ohio, now changed his career, fortunately for science. He entered upon the numerous duties of his new position at the beginning of 1857, and for nine years devoted himself to this work of teaching, with little opportunity and presumably with little apparatus for research. He established a time-service for the neighboring city of Cleveland, but it does not appear that he made astronomical observations to any considerable extent. During several summer vacations at this time he acted as astronomical assistant on the government's lake survey, being chiefly engaged in telegraphic determinations of longitude.

In the summer of 1857, shortly after he began his work at Hudson, he was married at Concord, New Hampshire, to Miss Augusta S. Mixer. She was a woman of unusually gentle disposition and character, understanding well how to enliven her husband when he was depressed with his many cares and responsibilities. Their singularly happy union continued for nearly forty-four years, until broken by her death in 1901. Their children, a daughter and two sons, were born while they lived at Hudson.

In 1862 the teacher left his classroom duties, in prompt response to the call of the governor of Ohio for volunteers, and was for four months captain in the 85th Regiment of Ohio, his company B being chiefly constituted from the students of the college. The company did not see actual service in battle, but was detailed to duty in guarding prisoners, and later escorted a large number of prisoners to Vicksburg to be exchanged. Professor Young's health was somewhat impaired by this patriotic service.

In February 1866 he accepted the call to the professorship of natural philosophy and astronomy at Dartmouth, succeeding his father after a lapse of eight years. This particular chair had been sufficiently endowed so that quite a large collection of apparatus, particularly in optics, had been acquired for lecture use. Fortunately for the teacher, the method of laboratory instruction had not at that time been introduced in America; otherwise he could hardly have found time for the researches which marked the next few years, and established his position as a leader in the rapidly developing branch of solar physics.

His published writings on this topic began, so far as known, with a series entitled "Spectroscopic Notes," published in the *Journal of the Franklin Institute*, the first of which was dated July 19, 1869. He was provided with a spectroscope having five prisms of 45° attached to a four-inch telescope equatorially mounted. With this he carefully studied the spectrum of the chromosphere, and watched with a natural interest the strange forms of the prominences, the methods for observing which had been simultaneously announced by Lockyer and by Janssen only in the year preceding. These "Spectroscopic Notes" were eight in number, the last dated November 1870. They are brief and to the point. The second recorded drawings of the prominences, and the third was accompanied by a quite satisfactory lithographic reproduction of ten sketches, which have since been widely copied. He refers in the second note to his first observation of the bright lines of the chromosphere extending in upon the disk. In the fourth he describes his first study of the spectrum of a sun-spot, finding the C and F lines reversed and many lines widened, as had already been recorded by Lockyer. Young expresses his surprise at the prominence of the lines of titanium in the spot spectrum, which was also true of certain calcium lines. On September 22, 1870, he saw the sodium lines D_1 and D_2 reversed in the umbral spectrum. He adds: "At the same time the C and F lines were also reversed, but with the great dispersive power of my new spectroscope I see this so often in the solar spots that it has ceased to be remarkable."

Two days after he sent this communication to the editor of the *Journal of the Franklin Institute*, he wrote again announcing his success in obtaining a photograph of protuberances on the sun's

limb, using "the hydrogen line near G" ($H\gamma$). A wood-cut was made from the photograph, but, with the modesty which was always characteristic of him, he says:

> As a picture the little thing amounts to nothing because the unsteadiness of the air and the maladjustment of the polar axis of the equatorial caused the image to shift its place slightly during the long exposure of three and a half minutes which was required, thus destroying all the details. Still, the double-headed form of the prominence is evident, and the possibility of taking such photographs is established.

This was the first photograph of a prominence obtained anywhere, and it prepared the way for the developments which have made the photography of the prominences to be a daily routine at observatories concerned with the sun.

Professor Young describes in his fifth note the new form of spectroscope he designed for solar work, having the dispersive power of thirteen prisms, the light passing first through the lower portion, and then back through the upper portion of a train of six prisms. The apparatus was made by Alvan Clark and Sons, and Professor Young expresses his admiration "for the exquisite workmanship of the 43 different surfaces by which the light is either refracted or reflected on its way from the slit of the collimator to the eye." The writer can add his testimony to the delight in the use of the same instrument, practically unchanged, nearly twenty years later, and it is still of excellent service despite the improvements of spectroscopes with the general application of the diffraction grating.

The eighth spectroscopic note gives in a dozen pages an admirable statement "on the construction, arrangement, and best proportions of the instrument with reference to its efficiency." The advantage of using a half-prism at the beginning of a train is pointed out, and a simple form of chemical spectroscope is proposed in which flint half-prisms are cemented directly to the single crown lenses of collimator and observing telescope, the back surface of the prism being made concave to fit the lens. The plan is a very good one and has recently been applied in celestial spectroscopes.

With keen interest in the study of the chromosphere and prominences, stimulated and made possible by the far-reaching results of the spectroscopic observations of the solar eclipse of 1868, it was

natural that Young should wish to observe the eclipse of August 7, 1869. He became a member of the party organized by the U. S. Naval Observatory, under the charge of Professor J. H. C. Coffin of the Nautical Almanac Office. The station was at Burlington, Iowa, and was favored by fine weather, so that excellent results were secured. An interesting account of this eclipse was contributed by Professor Young to the *American Journal of Science* for September 1869, under the title "On a New Method of Observing Contacts at the Sun's Limb, and on Other Spectroscopic Observations during the Recent Eclipse." Half an hour before totality he conceived the idea of observing the contact through the spectroscope set radially upon the sun's disk, and watching the bright C line shorten under the approach of the moon; he was gratified at the realization of his plan, and he felt confident that his observed time of contact must be accurate within a second. He suggested the application of the method to the case of the transit of *Venus* of 1874 for which preparations were already in mind. He later found that this proposal had been made to the French Academy by Faye in January of that year.

Young examined during the totality the spectrum of prominences which he had located earlier in the day: C was brilliant, the next to it was "the orange line, which for convenience I will call D_3." Then he noted that the line 1474 K extended clear across the spectrum, and persisted when the slit was moved away from the protuberance. "Thus it was evident," he states, "that this line belonged, not to the spectrum of the protuberance, but to that of the corona." He also noted a faint continuous spectrum, without dark lines, "evidently due to the corona." The apparent coincidence of three coronal lines with lines located by Winlock in the spectrum of the aurora led Young to entertain the view that the phenomena of corona and aurora were related, with 1474 K in particular present in both. He did not assert the relationship with any positiveness, stating: "I do not feel in a position to urge it strongly, but rather await developments." Although he soon saw the error, it was long before it could be suppressed, after once gaining currency. There was much discussion as to the origin of the characteristic corona line 1474 K, Lockyer regarding it as due to iron, Secchi as due to hydrogen. The matter was not really cleared up until the Indian eclipse of 1898, when both Lockyer and Campbell

found that the wave-length of the corona line is actually a trifle less (λ 5304 on Rowland's scale) than 1474 K (λ 5317). The latter is, as Young found, a characteristic chromospheric line, and is probably due to iron.

In view of the interesting discoveries at the eclipses of 1868 and 1869 it is not surprising that a strong party of American observers, under Professor Winlock, including Professors Langley, Pickering, and Young, was prepared to study the phenomena of the eclipse of December 22, 1870, at Jerez in Spain. Better favored than most other parties, they had a chance for observations at totality, through a break in the clouds. Young's discovery of the 1474 line as due to the corona was fully confirmed; it was followed out beyond the limb for a distance of more than half the solar radius, and it was seen to be the brightest of the lines. Let us now quote from Young's own words:

> No new lines were observed with which I was not before familiar. But just at the commencement of the totality I made an observation, which was wonderfully beautiful to see, and which, I think, has important theoretical bearings. The slit of my spectroscope was placed tangential to the sun's limb, just at the base of the chromosphere, the 1474 line on the cross-wires. As the crescent of the sun (or decrescent, rather) grew narrower, this line, and the magnesium lines close by, as well as some others in the same neighborhood which I am accustomed to see bright in prominences, gradually increased in brilliancy, when suddenly, as the last ray of the solar photosphere was stopped out by the moon, the whole field of view was filled with countless bright lines—every single dark line of the ordinary spectrum, so far as I could judge in a moment, was reversed, and continued so for perhaps a second and a half, when they faded out, leaving only those I had first been watching. This points to an atmosphere of heated vapor some five or six hundred miles in thickness above the photosphere, and tends to make Kirchhoff's original theory of the constitution of the solar surface again tenable.

This is from his interesting account of the eclipse written on the next day for the college paper, *The Dartmouth*, to which he had previously contributed an exceedingly readable narration of his visits *en route* at Gibraltar and Tangier. In his letter to Professor Morton for the *Journal of the Franklin Institute*, also written on December 23, he states his discovery of the reversing layer very clearly:

> But the most interesting spectroscopic observation of the eclipse appears to me to be the ascertaining, at the base of the chromosphere, and, of course, in immediate contact with the photosphere, of a thin layer, in whose spectrum *the dark lines of the ordinary solar spectrum are all reversed.*

The phenomenon was also seen, for an instant only, by Mr. Pye, a young Englishman, who assisted Professor Young, using one of his spectroscopes.

The objective reality of this phenomenon was not fully confirmed until Mr. Shackleton, of Sir Norman Lockyer's party at Nova Zembla, a quarter of a century later, obtained the first successful photograph of the "flash spectrum" at the eclipse of August 9, 1896. Since then it has been photographed by many observers at most of the eclipses favored with clear skies.

The problem of the solar corona occupied Professor Young's mind for some time after the eclipse, and in May 1871 he published in the *American Journal of Science* a paper "On the Solar Corona," supplemented by a note on its spectrum, in the July number. After the lapse of nearly forty years there is little to be added to his presentation of the complex nature of the spectrum and the probable sources of its constituents.

A lecture delivered before the Yale Scientific Club, on "The Sun and the Phenomena of Its Atmosphere," was published as a booklet of duodecimo form of 55 pages in 1872. It probably was not widely circulated, but it formed the basis of his classic, *The Sun*, of the International Scientific Series, which appeared in 1881. His observational activities were still chiefly directed to the sun, although he printed in *The American Journal of Science* in 1870 an account of "a new method of determining the level-error of the axis of a meridian instrument;" and of observations of the spectrum of Encke's comet, which was faintly visible to the naked eye in December 1871. At this time he had a 9.4-inch Clark equatorial for his work. The observations of the cometary spectrum were consistent and reliable, and could hardly be improved upon today with a similar telescope and the visual method.

Four weeks of work in the autumn of 1871, nearly at the time of a solar maximum, sufficed for a preliminary catalogue of the bright lines Young saw in the spectrum of the chromosphere, 103 in number. He called attention to the abundance of titanium lines, which constituted one-fifth of the whole number reversed. The advantage of a high elevation, with diminished reflection from our atmosphere, was apparent, and in the summer of 1872 Professor Young, under the

auspices of the U. S. Coast Survey, made an expedition to Sherman, Wyoming, on a high plateau about 8300 feet above sea-level, where he set up his telescope and spectroscope and added 170 to his list of chromospheric lines. He states that the elevation gave

> even greater advantages for my special work than had really been expected, although I was never quite able to realize my *hope* of seeing all the Fraunhofer lines reversed, unless once or twice for a moment, during some unusual disturbances of the solar surface. Everything I saw, however, confirmed my belief that the origin of the dark lines is at the base of the chromosphere, and that the ability to see them all reversed at any moment depends merely upon instrumental power and atmospheric conditions.[1]

An observation very important in its bearing upon the future development of the study of the surface of the sun is mentioned at the end of this brief paper. Referring to the fact that the calcium lines H and K were both reversed, as constantly as *h* or C when the seeing was good, he adds: "They were also found to be regularly reversed upon the body of the sun itself, in the *penumbra and immediate neighborhood of every important spot*" (italics his).

Professor Young made a comparison of the solar outbursts observed at Sherman with the magnetic records at Greenwich and Stonyhurst, and regarded it as probable that every solar disturbance receives an immediate response from the earth, and that the magnetic impulse travels, sensibly, with the velocity of light. It is surprising that this question is still under discussion after every case of marked "earth-currents" or an unusually brilliant aurora: the probabilities are perhaps as much in accord with Young's view as ever.

The coming transit of *Venus* was now exciting the interest of astronomers. Professor Young was asked to take charge of a party to be stationed at Kerguelen Island, but was unable to leave his teaching for the necessary length of time. He did, however, join the party under Professor J. C. Watson at Pekin, which secured results satisfactory at the time, before the comparative futility of that mode of determining the sun's distance was appreciated.

At about this time Professor Young contributed semi-popular articles on solar phenomena to the *Popular Science Monthly* and

[1] This has now been practically realized at the Mount Wilson Solar Observatory. See the paper by Hale and Adams entitled "Photography of the 'Flash' Spectrum without an Eclipse," *Astrophysical Journal*, **30**, 222, 1909.

other serious reviews, and wrote for *Johnson's Cyclopaedia* the articles on "Sun" and "Spectroscope." It must be remembered that during all of these years at Dartmouth he was teaching physics as well as astronomy to every third-year student in the college, and was giving annual courses of lectures at two or more schools for young women, beside many popular addresses.

He had promptly appreciated the advantages of the diffraction grating when he saw those ruled by Rutherford, who later placed some at his disposal. He then detected the duplicity of the 1474 line, thus apparently clearing up the outstanding difficulty as to the origin of the corona line, which he never could accept as an iron line. In the summer of 1876, with a good grating, he applied Doppler's principle to the rotation of the sun and obtained the first good quantitative results by the method.[1] He hoped to use the atmospheric lines as reference points, but found those he tried "too faint and shadowy;" he therefore set his wires alternately upon the east and west limbs of the sun and measured the differences, obtaining for the velocity of the sun's rotation 1.42 miles (2.29 km) per second, while the value derived from observations of sun-spots was 1.25 miles or 2.01 km.

In the summer of 1877 Professor Young accepted a call to the professorship of astronomy at Princeton with the assurance of a fine modern equipment and less time required for the classroom. His special appreciation of instruments and his well-balanced judgment as a teacher contributed to the establishment within a short time of the best astronomical observatory for instruction provided up to that time. But in spite of the energy necessarily required for this new construction, Professor Young was active in research as well as writing. In 1878 he conducted a Princeton party to Denver to observe the eclipse of July 29. It was the plan to investigate the spectrum of the corona and chromosphere, especially in the infra-red and ultra-violet, but the results, at this time of minimum solar activity, were less than had been expected, although the day was fine: the corona line and others were far less conspicuous than at eclipses during a solar maximum.

In the following year he made quite an extensive series of micro-

[1] Vogel had made the experiment in 1871 with less dispersion, but his results could not be very accurate.

metric measures of the polar and equatorial diameters of *Mars*, using the excellent 9½-inch equatorial; the satellites were frequently seen with that instrument. Cometary spectra were also observed as they presented themselves in sufficient brightness, including Brorsen's (1879), Hartwig's (1880), and the great comets of 1881 and 1882.

By 1882 the excellent 23-inch Clark refractor was set up in the Halsted Observatory and provided with a powerful solar spectroscope, for his researches.

An extended programme for the transit of *Venus* on December 6, 1882, was carried out under somewhat unfavorable weather conditions at Princeton, micrometric, spectroscopic, and photographic observations being included.

Professor Young contributed to the *American Journal of Science* two further papers entitled "Spectroscopic Notes," in November 1880 and November 1883. Though brief, they are important: the first deals with the H line in the chromosphere; with the successful resolution of lines given on maps as common to two different elements ("basic lines"); with the distortion of solar prominences in a diffraction grating spectroscope, and deriving the formula therefor; he adds a note on an immense prominence, over 350,000 miles high. The second paper gives results with a powerful spectroscope of the Littrow type attached to the 23-inch telescope, whereby he resolved "the spot spectrum into a congeries of fine (dark) lines," an observation which has since been fully confirmed with yet more powerful apparatus.

He had at about this time some exchange of opinion with a prominent English observer on the subject of large versus small telescopes. Admitting as "sadly true" the greater susceptibility of large instruments to atmospheric disturbances, he finds it also true

> that I can almost see with the 23-inch everything I can see with the 9½-inch under the same atmospheric conditions, and see it better; if the seeing is bad, only a little better; if good, immensely better. . . . . Under higher powers, also, markings which are conspicuous with lower ones often disappear in the same way that the naked-eye markings on the moon vanish in the telescope. Most commonly, however, when I have failed to see with the large instrument anything I supposed I saw with the smaller, it has turned out on examination that the larger instrument was right, and that imagination had constructed a

story that was not true, by building up faintly visible details and hazy suggestions furnished by the smaller lens.[1]

In 1892 when the Halsted Observatory received its new spectroscope by Brashear with a fine Rowland grating, Professor Young undertook the work of revising his list of chromospheric lines; ill-health and other causes delayed the work so that it was never entirely completed, but it was published as "a partial revision" in 1894 in the edition in English of Scheiner's *Astronomical Spectroscopy*. This was his last extensive piece of observational work on the sun. His other observations with the 23-inch telescope dealt with the planets, with certain double stars, and with the spectrum of *Nova Aurigae*.

A beginning was made in stellar spectrographic work with the new instrument, using both a grating and prisms, but attacks of sciatica had reduced his capacity for prolonged night work, and the lack of a regular research assistant at the Halsted Observatory prevented a continuance of investigations in this field.

Solar eclipses very naturally retained his interest and he was enabled by the generosity of friends to take a small party to Russia for the eclipse of August 19, 1886. The station selected by Professor Struve for this party was not very far from Moscow, but like most other points along the track of totality, it suffered from very bad weather, and no observations were possible. However, the trip gave Professor Young an opportunity to visit the leading observatories of Europe, renewing many friendships and establishing new ones, and he gave a very interesting account of it in *Scribner's Magazine* for July 1888 under the caption "An Astronomer's Summer Trip."

At the eclipse of May 28, 1900, Professor Young organized quite a large party from Princeton and established a station at Wadesboro, North Carolina. The weather was very favorable and excellent results were obtained, but the corona line was too faint for carrying out the programme Professor Young had prepared in that respect.

During these years Professor Young was delivering many addresses, and he always took such responsibilities very seriously, unnecessarily so, indeed, in later life. A lecture upon a topic somewhat out of his regular line would often lie heavily upon him for weeks until satisfactorily worked out. His address as vice-president of Section A

[1] *The Observatory*, **8**, 172, 1885.

at the Buffalo meeting of the American Association for the Advancement of Science in 1876 was upon the topic "American Astronomy, its History, Present State, Needs, and Prospects;" as retiring president of the association at the Philadelphia meeting in 1884 he discussed "Pending Problems in Astronomy" in a masterly fashion. He delivered the principal address at the opening of the Kenwood Observatory at Chicago in 1891.

He felt no shame in accurately popularizing science, and responded frequently to the invitations of the editors of the magazines. He also occasionally wrote at the request of the editors of New York newspapers, which did not at that time crave sensational articles so much as now. Probably the financial stress, so familiar (and perhaps ultimately beneficial) in the experience of college teachers, was also a partial motive for some of these contributions.

He contributed for Professor Newcomb's admirable *Popular Astronomy* a statement of his views upon the constitution of the sun; and at the request of Professor Vogel, editor of the third German edition of that work, he revised that statement to correspond with the increase of our knowledge up to 1904. This was also printed in English in the magazine *Popular Astronomy*.

In 1884, in conjunction with Professor E. C. Pickering, he edited for the *Proceedings* of the American Academy of Arts and Sciences the researches of the late Dr. Henry Draper on astronomical spectrum-photography.

Professor Young's reputation as an author, already well established by his many semi-popular articles, was widened still more on the appearance in 1881 of his book on the sun, which at once took a commanding place among works of its class; while it is a volume constantly needed by specialists in solar physics, it is written in such a simple and interesting manner as to attract and hold the intelligent general reader. It has passed through several editions, and has been translated into foreign languages.

His rare experience as a teacher was finally crystallized in his *General Astronomy*, which appeared in 1888 and was widely adopted in college use. It emphasized one of his fundamental pedagogical principles, that the things taught "must be correct and accurate as far as they go." It contains ideas suggestive to the investigator,

as well as teacher and student, and did much to encourage accurate thinking on the part of pupils who have studied it. The successive issues of the book were altered and enlarged by notes until a revised edition was necessary in 1898. Nearly 30,000 copies of this work have been printed. It called, however, for some rather difficult thinking for students not specializing in science, and a more elementary book entitled *The Elements of Astronomy* (with uranography) appeared shortly thereafter, and was used still more widely in schools and colleges. Responding to the demand for a work available for quite young pupils, the *Lessons in Astronomy* appeared in 1891, and over 60,000 copies have been sold. A textbook intermediate between the *General Astronomy* and the *Elements* seemed to be needed, and was issued in 1902 under the title of *Manual of Astronomy*. It is a handsomer book than the *General* and omits little of importance that is contained in the latter. An edition revised by his niece, Miss Anne S. Young, professor of astronomy in Mount Holyoke College, is now appearing.

The very considerable labor involved in the preparation of these textbooks was not given at the expense of research, as the condition of Professor Young's health had prevented him from much observing after the early nineties. By a strict regimen he kept in check the inroads of a very serious disease, from which his physician could pronounce him as practically recovered only a very short time before his death.

His influence as a teacher was greatly widened by the large use of his textbooks, and the position of authority which they gave him carried with it the burden of an increasing correspondence and the answering of many queries from all sorts of readers. He was also consulted very generally by teachers planning new equipment, by young men undertaking spectroscopic work, and by the many who valued his scientific and educational experience.

Upon the establishment of THE ASTROPHYSICAL JOURNAL in 1895 he became a member of its advisory board of associate editors, a relation maintained, under that name or as collaborator, until his death.

Insufficient allusion has been made to Professor Young's appreciation for and skill in mechanical matters. He devised an improved

clock escapement which has performed satisfactorily for many years at Princeton, and a suggestion of his is incorporated in most of the conical pendulum driving-clocks in use in this country. In practical astronomy he would have made more contributions had his time not been occupied with solar physics; but he proposed a method of investigating pivot errors, detected the serious effect of flexure in the "broken transit" and showed how it could be corrected, and investigated in his own way the color-correction of achromatic object-glasses. He also wrote on such physical topics as "Mr. Edison's Dynamometer, Dynamo-Machine and Lamp," and he kept abreast with the new discoveries of physics and related branches of science.

Professor Young's personal characteristics were so obvious that it would be superfluous to describe them to his friends; to those who missed the opportunity of knowing him, it may be said that he was thoroughly infused with the true scientific spirit—ever ready to modify theory to accord with newly discovered facts, and to accept the revision of what were once the best facts available as new information was obtained by experiment and observation. He was entirely free from the dogmatism that often grows upon men with an enlarging reputation as authorities upon a subject. His modesty, even humility, in the consideration of the laws of nature, was a true characteristic of his greatness. This impressed itself upon his thousands of students, and upon the many auditors at his lectures. As a teacher, his methods and manner were simple and straightforward; his remarks were enlivened by a quaint humor which also pervades his writing. He took a genuine interest in his pupils and it was remarkable how quickly he learned and retained the names of the members of the large classes which always attended his courses, attracted probably more by the teacher than by the subject.

Professor Young was small of stature, growing a trifle stout in later life; he was not especially fond of physical exercise and had no hobbies in the way of recreation, but he took a real interest in college sports. The writer has a very distinct mental picture of him in the early seventies, playing on his well-kept lawn the then popular game of croquet, for which several of his colleagues regularly gathered. He always aimed at skill in whatever he undertook. At Princeton

he found recreation in whist, playing a good hand on an occasional evening.

The life in his home was ideal, and its gentle courtesy is remembered by the many who were welcomed to its cheer. Astronomers from foreign countries, traveling in America, always included a visit to Princeton in their itinerary when possible, of course far more to see the man than the excellent observatories under his charge.

Mrs. Young was a singularly attractive woman, who playfully diverted her husband's mind from his work when he was off duty, and by her devotion to him and attention to details, gave him the opportunity for performing his many duties with as little disturbance as possible. Her failing health greatly depressed him, and her death in 1901 was a blow from which he could not recover. Other serious anxieties and sorrows came to him before this: the dangerous accident to his oldest son from an electric shock, causing paralysis from which recovery was long doubtful, and never complete; the death of his daughter's husband, Professor Hiram A. Hitchcock of Dartmouth, after a short married life.

Upon reaching the age of seventy, in December 1904, Professor Young sent to the trustees of Princeton his resignation, to be effective in the following June, when his service of 28 years would be completed. Evidences of appreciation of his long and useful service, and of his own personality, came to him from all directions during the remainder of the academic year, and brought much quiet satisfaction to him. He was made professor emeritus, and also came under the provisions of the retirement fund of the Carnegie Foundation.

A farewell dinner, which brought out in a striking manner the unusual feeling of regard for him on the part of his colleagues and the university authorities, was given him on May 17, 1905, and a handsome silver loving cup was presented to him. At commencement, a month later, the degree of Doctor of Laws was conferred upon him at Princeton, with further expressions of deep feeling.

He returned to his early home at Hanover, where his daughter, with her son, lived with him. The enfeebled condition of his health did not permit him to undertake much work, however, and he again was afflicted by the long illness and death of his daughter. During the last months of his life he was recovering from the Bright's disease

which had beset him for years, and there was hope that he might have some period of health, but after a brief attack of pneumonia he died peacefully on January 3, 1908, at the age of seventy-three years and nineteen days. He was survived by two sons, and by a grandson.

Many honors naturally came to him during his career. He was made associate of the American Academy of Arts and Sciences in 1869, of the Royal Astronomical Society in 1872, and later of the philosophical societies of Manchester, and of Cambridge, England, and of the Società degli Spettroscopisti Italiani. He became a member of the National Academy of Sciences in 1872, and of the American Philosophical Society in the same year. He was made a foreign correspondent of the British Association for the Advancement of Science in 1887. In 1891 he received the Janssen medal of the French Academy of Sciences for his spectroscopic researches. Honorary degrees were bestowed upon him liberally—that of Doctor of Philosophy by Pennsylvania in 1870, and by Hamilton in 1871; that of Doctor of Laws by Wesleyan in 1876, Columbia in 1887, Western Reserve in 1893, Dartmouth in 1993, and Princeton in 1905.

Throughout his whole life Professor Young retained the strong religious conviction of his youth: he was essentially a man of faith. There was not to him any serious antagonism between the fundamentals of science and of religion. This position gave him considerable influence among those having to do with theological instruction; and, on the other hand, it had its useful effect upon his many college students, who had for him only the highest respect.

Not a few of his pupils have taken up astronomy professionally or as teachers: through them, both consciously and unconsciously, and through his writings, his influence perpetuates itself—in research, education, and the public enlightenment.

YERKES OBSERVATORY
1909

THE RESONANCE AND MAGNETIC ROTATION SPECTRA OF SODIUM VAPOR PHOTOGRAPHED WITH THE CONCAVE GRATING

By R. W. WOOD and FELIX E. HACKETT

The fluorescence and magnetic rotation of sodium vapor have been the subject of an extensive investigation by one of the present writers.[1] This paper deals with the further study of the phenomena under a higher dispersion than has been hitherto employed. In order to set forth more clearly the scope of the present investigation, a short account of the results which have been obtained in the previous work will be given, but for further information original papers must be consulted.

The fluorescent spectrum of sodium vapor excited by white light consists of a region in the orange-red and another in the greenish-blue with a broad double band in the position of the D lines. When the vapor is dense, the spectrum in the red is seen to be distinctly banded. In the course of the present work it was found that the red and orange lines of lithium excite fluorescence in the red, but as these are the only monochromatic sources thus far found which do so, it has not been possible to make a detailed study of this region. A large number of metallic arcs, however, have been found capable of causing fluorescence in the greenish-blue. In some cases several lines in the arc are active, but wherever it was possible to isolate an exciting line, the spectrum of the fluorescence was found to be comparatively simple and to consist of widely separated lines, most of which were placed at nearly equal intervals along a normal spectrum. In the earlier work, a three-prism spectrograph was used and the wave-lengths could not be determined within 2 Å. U. with the dispersion which it gave. The intervals varied between 34 and 38 Å. U. Later work has shown that the intervals are still more constant, averaging 38 Å. U.

[1] Wood and Moore, *Astrophysical Journal*, **18**, 94, 1903; Wood, *Philosophical Magazine*, **12**, 499, 1906.

The vibrating system in the atom in the present case has such a constitution that it is capable of absorbing monochromatic radiation of a certain frequency and re-emitting a great part of it as radiation of the same frequency, combined with other related frequencies. The phenomenon may be considered as a case of light resonance. On this account it seems well to call the fluorescent spectra due to monochromatic stimulation resonance spectra. Light re-emitted without change of wave-length we may call resonance radiation. The simple relation existing between the wave-lengths in these spectra makes them a most interesting addition to the phenomena of radiation. The series which have been discovered in the emission spectra of the elements have more complex formulae, and the inference that the members of one series form part of the same electro-mechanical system, though very plausible, has been disputed. But the lines in the resonance spectra must belong to the same system since they are all due to single exciting lines. It is of great importance to know the exact law connecting their frequencies, for this is a characteristic of the type of the system. As Professor Larmor has pointed out, a non-radiating system of electrons in steady orbital motion when disturbed by the absorption of a radiation corresponding in frequency to the frequency of one of the electrons should then emit radiations consisting of equidistant frequencies, whose spacing was equal to the frequency of the period of the orbital motion. This holds in general for any dynamical system of particles which form a rotating ring. Further it has been shown by Stephenson[1] that any dynamical system, in which the restoring force is a periodic function of the time, will give forced oscillations with equidistant frequencies. He has put forward such a system as a model for the sodium atom in regard to fluorescence. These results have greatly increased the interest of the present work of determining more exactly the wave-lengths of the fluorescent lines. The earlier work had still left it open to question whether the apparent equi-spacing of wave-length is an exact law, or is only a first approximation to a more complicated relation such as an equi-spacing of frequencies as exists in the above-mentioned dynamical system.

It may be stated here that the present values for the wave-lengths

[1] *Philosophical Magazine*, **14**, 115, 1907.

have fully confirmed the first opinion that the regularity in the resonance spectra was an equi-spacing of the *wave-lengths* of the series.

These relations between the wave-lengths in the fluorescence alone would be a very incomplete contribution to the data necessary for the solution of the problem of constructing a model of the radiating mechanism in the atom which gives the fluorescence. It is also necessary to have some information about the elements which are vibrating. The Zeeman effect along the lines of force in the magnetic field has shown that a great many lines in the emission spectra of the elements are due to the vibration of negative electrons and this inference has been implicitly extended by many writers to all spectral lines. The direction of the magnetic rotation at an absorption band also serves to yield similar information for absorption bands. From the theory of this phenomenon it has been shown that the magnetic rotation at the D lines in sodium vapor is due to negative charges. The same is true at the ultra-violet lines which with the D lines form the principal series as shown by one of us.[1] A more extended investigation of the magnetic rotation spectrum has enabled some conclusions to be drawn concerning the nature of the vibrating system for nearly all the fluorescent lines.

When plane-polarized white light is passed through sodium vapor in a magnetic field along the lines of force, a nicol prism, set to extinction in the absence of the magnetic field, will now transmit a brilliant orange-yellow light. When this light is analyzed in the spectroscope it is seen to consist of a great number of bright lines in the greenish-blue and red with a narrow bright region of continuous spectrum near the D lines. The latter is simply the normal magnetic rotation of all the region of the spectrum near the D lines and has been the subject of a previous investigation.[2]

The lines in the red and green make up the magnetic rotation spectrum. It has been shown that they are narrow regions, possibly less than a tenth of an Ångström unit wide, in which the light has been rotated through varying degrees, enabling it to pass through the

[1] Wood, *Philosophical Magazine*, **10**, 408, 1905; **14**, 145, 1907; **15**, 274, 1908.

[2] Wood, "The Ultra-violet Absorption, Fluorescence, and Magnetic Rotation of Sodium Vapour," *ibid.*, **18**, 530, 1909.

nicol. An account has been given of the attempts which have been made to determine the direction and magnitude of the rotation in these lines. Success was finally attained by using a Fresnel double quartz prism in combination with two nicols. A full account of the method has already been given. By this means it was discovered that the magnetic rotation spectrum in the red consisted in part of lines rotated in the same direction as the D lines and in part of lines rotated in the opposite direction. The simplest conclusion would be to say that the latter are due to the vibrations of positive electrons. This is a point, however, which must be considered as unsettled at the present time. In the present work the foregoing method was used both in the red and green. The method is quite successful in the red, and the wave-lengths of the magnetic rotation lines in this region have been measured and their direction of rotation determined. In the green the method was not so successful, and another method was devised which has given the direction of rotation of the lines in this region also. The wave-lengths of the principal rotations have already been obtained from photographs with the 14-foot grating. The spectroscope used in the present investigations gave a brighter spectrum and a great many additional lines were obtained. These lines have enabled the scheme of five series, drawn up in the earlier paper, to be greatly extended. The improvement in the measurement of the wave-lengths of the resonance spectra has brought out more clearly relations existing between the magnetic rotation and the fluorescence, so that it has been possible to infer whether the series in the resonance spectra are due to negative electrons or not.

APPARATUS

We shall now proceed to a detailed account of the investigation and a description of the several spectra.

There has been no essential modification of the apparatus used in the previous investigations. The sodium vapor is heated in an exhausted steel tube thirty inches long and three inches in diameter with its ends closed by plate-glass cemented with sealing wax, the ends of the tube being cut slightly oblique, so as to avoid reflection from the plates. A steel retort at its center, in which a large amount of sodium can be stored, was made from a piece of short steel

tubing (which could just slip into the long tube), by fitting a circular disc with an oval aperture at its center to each end. Additional sodium could easily be introduced into the retort, without removing it from the tube, through the aperture by means of a pointed brass rod. The tube was exhausted by means of a Fleuss pump and heated by a large burner; the ends were kept cool by tightly wound coils of lead piping through which cold water circulated. A short column of strongly heated sodium vapor was thus obtained in the retort, from which it slowly diffused through the aperture, condensing on the colder walls of the tube before it reached the glass windows.

The exciting beam of light was brought to a focus just within the retort, and the fluorescence viewed against a black background obtained by smoking the second window. A small silvered glass mirror about 1 cm square placed before the first window deviated the fluorescent light through an angle of 90° from the direction of the exciting beam of light and it was concentrated by means of a short-focus lens on the slit of the spectrograph.[1] This consisted of a 12-foot concave grating, ruled with 14,438 lines to the inch, used with a 6-foot collimating lens. With this combination the focal curve at the camera was practically a straight line within the region under investigation, so that it was possible to use plates. As the most important region of the fluorescence in the green lies at about $\lambda = 5100$, the grating was turned so that this region fell near the center of the plate. The plate-holder was 8 inches long and the region which could be photographed on one plate extended from 4500–6500. The camera was fitted with the usual rotating shutter device, for obtaining the comparison iron spectrum above and below the fluorescent spectrum.

On account of the greater dispersion, the fluorescent spectra were now much fainter than before and long exposures were necessary, extending in many cases to 20 hours. It was very important therefore to obtain the brightest possible fluorescence. As yet no exact investigations on this subject have been made, but a few general considerations may be mentioned. Pressure, temperature, and intensity of the exciting light are the three important factors. Fluorescence takes

[1] This materially increased the effective intrinsic intensity of the fluorescence as it now appeared strictly "end-on" when viewed in the mirror.

place only at low pressures and continues to increase in brightness with decreasing pressure. This was still noticeable when the pressure was reduced from 4 mm to 2 mm, the lowest pressure which could be obtained with the Fleuss pump, and which was the pressure used in the present work.

The fluorescence increases with increasing temperature, but it is evident that in this case a certain maximum will be reached. But even if this maximum is not reached, it must be noticed that the range of temperature which can be used depends on the dimensions of the apparatus and the efficiency of the water-jacket at the ends of the tube. The sodium vapor streams out from the retort gradually, condensing on the walls. It is necessary that the temperature-gradient along the tube should be great enough to cause all the vapor to condense before it reaches the glass window. Otherwise a white deposit forms on the windows and fogs them. For this reason a single large burner gave as high a temperature as could be safely employed, and if slightly displaced from the center a fog was sure to form on the nearer window after some time. The cold-water jackets cannot prevent this if the source of heat is too near one end, since there is a radial heat-gradient as well as a longitudinal one, and the former may be very large in a wide tube. The higher the temperature of the sodium vapor the longer the tube which must be used, and consequently the smaller the angular aperture of the glass window viewed from the retort. This limits the amount of light which can be thrown into the retort so that in this way there is not much advantage in raising the temperature after a certain stage is reached.

The fluorescence takes place through the whole path of the beam of light in the vapor, but it is brightest where the light rays converge to a focus. As most arcs wander over the electrodes, this bright spot of fluorescence is continually moving to and fro, causing a corresponding motion of the image on the slit. If the image be small, it may be for a great part of the time to one side or the other of the slit, so that the actual exposure is but a fraction of the apparent exposure. The fluorescent spot must then be large enough so that some part of the image will always be on the slit. Again the fluorescence takes place through the volume of the vapor, so that the best results with a given source would be obtained by having the maximum concentra-

tion through the volume and not only at a single point. Both conditions are satisfied if we form a large image of the arc in the retort, utilizing the full aperture of the tube. In practice the best working-conditions were obtained by trying several adjustments and different lenses to condense the light.

Where metallic arcs were obtained by using a cored carbon filled with the salt or metal as anode, it was sometimes necessary to prevent the glowing carbon from exciting white-light fluorescence in the retort. This was done either by placing an asbestos screen with a horizontal slit just in front of the arc, or by focusing the arc on a small hole in a screen, and throwing the image of this hole by means of a second lens into the retort. In the latter case the wandering of the arc could be observed on the screen, and correction made by moving it from side to side. In the former case an image of the arc was thrown on a screen behind the arc which served the same purpose.

Cramer's Instantaneous Isochromatic plates were exclusively used in photographing the fluorescence in the green, as they were found to be superior to any others which were tried, on account of their high and fairly uniform sensibility in this region. As even with the brightest fluorescence produced by monochromatic stimulation the plates were considerably underexposed, they were slightly fogged by a short exposure of 10 sec. at a distance of three feet from a very small gas flame and then strongly developed. The advantage of treating photographs of weak spectra in this way has recently been discussed and illustrated.[1]

SILVER EXCITATION

The results which have been obtained for each excitation will be discussed in detail and, at the end of the paper, a chart of all the series which have been obtained and a general summary of the relations of the different series will be given. We begin with the resonance spectrum due to the silver arc in which there is only one exciting line, λ 5209. The photograph with the 12-foot grating has recorded only six lines, though in the earlier work fifteen were obtained. But the new measurements of these six lines show a much more regular spacing. This is seen in the second column of the table, in which the

[1] Wood, *Astrophysical Journal*, **27**, 379, 1908.

differences between successive members of the spectrum is given. If we regard the fluorescence as a forced resonance due to the exciting line, then it is the relation of the different wave-lengths in the spectrum to the wave-length of the exciting line which is of interest. The almost constant spacing suggests that the wave-lengths can be represented approximately by the formula $\lambda = \lambda_0 \pm mk$, where λ_0 is the wave-length of the exciting line and k is the common difference and m is a natural number, 1, 2, 3, etc., which fixes the place of the line in the series. The value of k obtained by taking the difference between the exciting line and any other line is given in column III. The result of using the average value to calculate the wave-lengths of the series is given in column V.

I	II	III	IV	V
			m	$5209.6 \pm m\ 38.2$
5133	38.2	$76.6 = 38.3 \times 2$	2	5133.2
5171.2	38.4	$38.4 = 38.4 \times 1$	1	5171.4
5209.6	38.3	Exciting line	0	*5209.6*
5247.9	37.8	$38.3 = 38.3 \times 1$	1	5247.8
5285.7	37.7	$76.1 = 38.05 \times 2$	2	5286.
5323.4		$113.8 = 37.9 \times 3$	3	5324.2

The regularity which exists in the series is brought out almost equally well by the figures in any of the three columns, II, III, and V. The arrangement in the third column is preferable since it prevents a double discrepancy arising from an error in one wave-length and it is adopted in the tables for the other series. Instead of calculating the wave-lengths, the average value of the common difference, k, will simply be given.

Ten of the fifteen lines in the photograph of the spectrum obtained in the earlier work seem to fit into the series given above, the remaining four belong obviously to quite a different series. As these additional lines will be included also on the chart, a full table is given below. The series to which the exciting line belongs is marked *a* and the second series *b;* as there is no exciting line in this series, the shortest wave-length is taken as origin. The differences are not so constant as in the present determinations, especially in the first five lines, which are very faint and could not be measured with great accuracy.

Their position is shown on the chart (Plate X) on which intensities

are roughly represented by the length of the lines. In the case of the silver excitation the dotted lines are from measurements made on the earlier plate.

SILVER EXCITATION

Intensity	Wave-Length	Series *a*. $k=38$	Series *b*. $k=38$
1	4947·5 ? *a*	$261.5=7\times37.4$	
1	4985·3 ? *a*	$223.7=6\times57.3$	
1	5022·3 ? *a*	$186.7=5\times37.3$	
1	5059·5 ? *a*	$149.5=4\times37.5$	
1	5097 ? *a*	$112=3\times37.3$	
2	5122 *b*		
6	5133 *a*	$76=2\times38$	
2	5160 *b*		$38=1\times38$
8	5170.8 *a*	$38.2=1\times38.2$	
4	5198 *b*		$76=2\times38$
10	*5209* *a*		
2	5236 *b*		$114=3\times38$
8	5247 *a*	$38=1\times38$	
6	5285·7 *a*	$76=2\times38$	
4	5323·4 *a*	$117.5=3\times39.1$	

In the scale of intensity adopted throughout this paper 10 denotes the intensity of the exciting line and the relative intensities of other lines are expressed by numbers from 10 to 1.

LEAD EXCITATION

In the lead resonance spectrum, which is also excited by a single line λ 5006.1, there is a second series which is almost as strong as the principal series. In other words, a series of doublets is excited as has previously been shown to be the case with cadmium λ 5086. But these two series do not by any means include the whole twenty-seven lines which appeared on the plates. Some of these apparently can be arranged in a series as shown in the table on p. 348, but with a very much smaller spacing than is usual; for this reason this grouping can be regarded as tentative only. As the appearance of a second and even a third series, in addition to the principal series which includes the exciting line, occurs in most monochromatic stimulations, it will be convenient to include all these series under the general term of secondary series. Their differences given in the tables will be in general reckoned from the wave-length of the shortest member of the series. The lines on the original photograph are too narrow and faint to reproduce well. Their position is shown on the chart.

A cored carbon filled with metallic lead was used for the lead arc. By properly adjusting the current and size of the hole in the carbon, the arc could be kept playing between metallic lead and carbon cathode, and it showed no tendency to strike on to the carbon. The current used was about 7 amperes and the hole was 6 mm in diameter in a carbon rod whose diameter was 12 mm. The carbon became red hot and burned away until it formed only a narrow rim surrounding a bath of molten lead. As it burned away at the same rate as the lead evaporated, the arc when the carbon was once filled needed very little attention and ran very smoothly.

LEAD EXCITATION

Intensity	Wave-Length	Series *a*. $k=39$	Series *b*. $k=39$	Series *c*. $k=37.5$
2.....	4929.4 *a*	$77.1=2\times38.5$		
1.....	4964.4 *b*			
2.....	4967.5 *a*	$39=1\times39$		
2.....	5003.4 *b*		$39=1\times39$	
10.....	5006.5 *a*			
2.....	5042.4 *b*		$78=2\times39$	
8.....	5045.2 *a*	$38.7=1\times38.7$		
2.....	5049.7			
6.....	5081.5 *b*		$117.1=3\times39$	
6.....	5084.2 *a*	$77.7=2\times38.9$		
4.....	5121 *b*		$156.6=4\times39.2$	
4.....	5123.7 *a*	$117.2=3\times39.1$		
4.....	5158.5 *b*		$194.1=5\times38.8$	
4.....	5162.4 *a*	$155.9=4\times39$		
2.....	5196.4 *c*			
6.....	5202.4 *a*	$195.9=5\times39.2$		
1.....	5226.3			
2.....	5233.4 *c*			$37=1\times37$
2.....	5240.4 *a*	$233.9=6\times39$		
1.....	5266.9			
3.....	5272.1 *c*			$75.7=2\times37.8$
2.....	5278.8 *a*	$272.3=7\times38.9$		
3.....	5300.4			
1.....	5309.7 *c*			$113.3=3\times37.8$
1.....	5337.3			
1.....	5365.6			
1.....	5372.2			

BARIUM EXCITATION

The barium line λ 4934 excites a beautiful series of equally spaced lines shown on Plate XI, Fig. 8, and in Fig. 13 with a portion of the magnetic rotation spectrum (14) in coincidence with it. The lines resemble the divisions on a centimeter scale, so regular is their spacing. The line λ 4934 is the bright line at the left of the plate. In addition

BARIUM EXCITATION

Intensity	Wave-Length	Series *a*. $k=38.8$	Series *b*. $k=38.4$
10	4554. *x*		
6	4562.1 *x*		
6	4574.6 *x*		
6	4580.3 *x*		
6	4599.2 *x*		
4	4606.9 *x*		
2	4673.8 *x*		
6	4691.5 *x*		
6	4726.5 *x*		
2	4756.8 *x*		
2	4761.2 *x*		
4	4860.9 *a*	$73.3 = 2\times36.7$	
2	4863		
4	4896.8 *a*	$37.4 = 1\times37.4$	
2	4900.5 *x*		
10	4934.2 *a*		
1	4935.7		
1	4937.4		
6	4972.8 *a*	$38.6 = 1\times38.6$	
2	5007.1		
4	5009.9		
6	5011.8 *a*	$77.6 = 2\times38.8$	
1	5046.9		
8	5050.3 *a*	$116.1 = 3\times38.7$	
1	5085.5		
1	5088.7		
8	5089.1 *a*	$154.9 = 4\times38.7$	
1	5091.1		
2	5123.4 *b*		
8	5128.5 *a*	$194.3 = 5\times38.8$	
6	5161.6 *b*		$38.2 = 1\times38.2$
3	5164.2		
6	5167.7 *a*	$233.5 = 6\times38.9$	
2	5192.6 *c*		
1	5193.8		
1	5198.2		
8	5200.0 *b*		$76.6 = 2\times38.3$
2	5202.6		
8	5207.2 *a*	$273 = 7\times39$	
1	5238.3 *b*		$114.9 = 3\times38.3$
2	5241.2		
4	5245.9 *a*	$311.7 = 8\times38.9$	
1	5267.4 *c*		
1	5274.3		
2	5277.6 *b*		$154.2 = 4\times38.5$
2	5286.5 *a*	$352.3 = 9\times39.1$	
1	5291.3		
1	5294 6		
1	5300.2		
2	5303.6 *c*		
1	5318.5 *b*		$195.1 = 5\times39.0$
1	5321.3 *a*	$387.1 = 10\times38.7$	
1	5331.8		
1	5336.6		

BARIUM EXCITATION—*Continued*

Intensity	Wave-Length	Series *a*. $k=38.8$	Series *b*. $k=38.4$
1	5339·5		
1	5341·1		
1	5354·3		
1	5425·3		
1	5443·3		

to these lines there are many others in the violet. There does not appear to be any series connected with them, but they have not the blurred appearance due to scattered light, and they have the same sharpness and intensity as the brightest fluorescent lines. It is therefore suspected that they form part of the complete resonance spectrum, and they have been included in the following table of the barium resonance spectrum, in which they are marked with an asterisk. The series which occur may be described as a more complicated version of the lead series. The lines which are apparently the first two members of the primary or *a* series have a spacing of only 37 Å. U. They have not been included in taking the general average for *k*. It is possible that the presence of the barium line λ 4900 may have had some influence on the spacing. The lines in the middle of the spectrum which have not been arranged in series are faint lines which occur as companions to the brighter lines, and a great number of lines at the end of the spectrum. The number of these faint unclassified lines is much greater than in the lead excitation. They seem to be fragments of a series which just appears for two or three members on either side of a principal series or even a strong secondary series and then disappears. Attention is directed to the two lines marked *c* in the table which form one such fragment. They are of interest in connection with the lithium excitation.

LITHIUM EXCITATION

The lithium arc stimulation is an important one, since we have four exciting lines: one in the violet λ 4603, a second in the green λ 4972, and two in the red λ 6104 and 6708. These lines are, however, so far apart that their resonance spectra do not overlap and can be studied separately. A photograph of the complete spectrum is shown on Plate XI, Fig. 5. The spectrum excited by the green line,

λ 4972, is an interesting one since its principal series almost coincides with the principal series of the barium line λ 4934. Comparing the wave-lengths in the two tables it will be seen that some are almost identical, and the average difference between corresponding members of a series is only 0.5 Å. U. But in the case of lithium, the principal

LITHIUM EXCITATION

Intensity	Wave-Length	Series *c*. $k=38.7$	Series *b*. $k=38.4$	Series *c*. $k=37.5$
4	4862.1 *a*	$110.0=3\times36.6$		
4	4896.5 *a*	$75.6=2\times37.8$		
10	4934.5 *a*	$37.6=1\times37.6$		
8	4972.1 *a*			
1	4978.4			
1	5006.8			
2	5010.9 *a*	$38.8=1\times38.8$		
1	5011.3			
8	5049.9 *a*	$77.8=2\times38.9$		
1	5080.7			
1	5085.0			
8	5089.0 *a*	$116.9=3\times39$		
1	5114.5 *c*			$77.3=2\times38.6$
2	5118.7			
1	5118.5			
2	5124.0 *b*			
1	5124.4			
8	5128.0 *a*	$155.9=4\times39.0$		
1	5129.5			
2	5152.8 *c*			$39.0=1\times39.0$
1	5153.4			
1	5162.1			
4	5162.4 *b*		$38.4=1\times38.4$	
4	5167.3 *a*	$195.2=5\times39.0$		
1	5167.8			
2	5191.8 *c*			
2	5198.6 *b*			
2	5206.9 *a*			
4	5229.5 *c*			$37.7=1\times37.7$
1	5237.7			
6	5266.7 *c*			$74.9=2\times37.4$
6	5304.3 *c*			$112.5=3\times37.5$

series soon disappears and its place is taken by the secondary series *c*, whose lines become stronger as we go up to the end of the spectrum. An inspection of the barium table reveals the existence of the two lines already mentioned which correspond to this lithium series. Likewise we find that the lithium spectrum has two lines which belong to the barium *b* series. It seems, therefore, to be fairly reasonable to conclude that we have the same vibrating system in the two cases, but

that the change in the frequency of the impressed oscillation has altered the distribution of intensity in the forced oscillations.

The disappearance of the principal series and the appearance of the secondary series can be best seen by referring to the chart (Plate X) on which the series are denoted by letters *a*, *b*, *c*, etc. The spacings on the chart should be studied with a pair of dividers.

It is worthy of note that the line λ 4934 in the resonance series one space below the exciting line (i. e., coinciding with the barium line) is stronger than the exciting line λ 4972. This is the only case in which this has been observed. It is moreover not the case in an earlier photograph taken with a small two-prism spectroscope, which is the one reproduced on Plate XI, Fig. 5.

The resonance spectrum excited by the λ 4603 line of lithium has not yet been obtained in a satisfactory condition for measurement. On the plate made with the 12-foot grating the series in the vicinity of the λ 4603 line (see Fig. 5) did not come on the plate at all, and the lines in the yellow-green (indicated by a ∽∽ in Fig. 5) and which owe their existence to the λ 4603 stimulation were too faint and hazy to permit satisfactory measurement. This work will have to be repeated.

MAGNESIUM EXCITATION

In the fluorescence excited by the magnesium arc we have the three lines of the green triplet acting together. These lines are so close together that it is not possible to obtain the excitation due to each separately. But it is quite easy to group the brightest lines in the spectrum in three principal series, *a*, *b*, *c*, one for each exciting line, as will be seen in the following table. Each line of the magnesium triplet excites a series of equally spaced lines, and these series taken together give a spectrum in which we find the triplet occurring at regular intervals—Plate XI, Fig. 10 (from an earlier photograph), and Fig. 11 (12-foot grating), on which only the strongest lines reproduce owing to the very narrow slit.

There does not seem to be any well-marked secondary series, though there seems to be what has been already called fragments of series associated with the series *c*. These have been indicated by the letters *d*, *e*, *f*, but it has not been considered worth while to tabulate their differences.

MAGNESIUM EXCITATION

Intensity	Wave-Length	Series *a*. $k=38.9$	Series *b*. $k=38.1$	Series *c*. $k=38.5$
4	4842.3 *c*			341.5 = 9×37.9
4	4865.8 *b*		307.1 = 8×38.4	
4	4878.2 *c*			305.6 = 8×38.2
4	4903.5 *b*		269.4 = 7×38.5	
4	4916.9 *c*			266 9 = 7×38.2
2	4931 4			
2	4947. *f*			
2	4953.9 *c*			229.9 = 6×38.3
2	4966.4			
4	4979.7 *b*		193.2 = 5×38.6	
4	4984.5 *f*			
4	4991.9 *c*			191.9 = 5×38.4
	5019.5 missing			
2	5022.7 *f*			
4	5030.2 *c*			153.6 = 4×38.4
2	5034.1			
2	5050 *a*	117.5 = 3×39		
2	5055.4 *g*			
2	5059.6 *b*		113.3 = 3×37.8	
2	5088.9 *a*	78.6 = 2×39.2		
4	5094.9 *g*			
4	5097.3 *b*		75.6 = 2×37.8	
1	5101.5 *d*			
6	5106.6 *c*			77.2 = 2×38.6
1	5110.8 *g*			
2	5124.5			
2	5128.3 *a*	39.2 = 1×39.2		
2	5133.7 *g*			
6	5135 *b*		37.9 = 1×37.9	
2	5139.8			
2	5142.4 *e*			
6	5145.1 *c*			38.7 = 1×38.7
10	5167.5 *a*			
10	5172.9 *b*			
1	5180.9 *e*			
10	5183.8 *c*			
8	5210.9 *b*		38 = 1×38	
2	5220.4 *e*			
8	5222.9 *c*			39.1 = 1×39.1
2	5245 *a*	77.5 = 2×38.7		
2	5249.2 *b*		76.3 = 2×38.1	
4	5257.1 *d*			
4	5262.3 *c*			78.5 = 2×39.2
1	5298.2 *e*			
1	5300.8 *c*			
1	5305.7			117 = 3×39

COPPER EXCITATION

The resonance spectrum excited by the copper arc is shown on Plate XI, Fig. 9, in coincidence with the barium excitation and in Fig. 16 in coincidence with the magnetic rotation spectrum.

COPPER EXCITATION

Intensity	Wave-Length	Series a. $k=38$	Series b. $k=38.4$	Series c. $k=38.7$	Series d_1 Series d_2
1	4812.3				
1	4814.2				
1	4823.5				
1	4825.4				
1	4839.1 a				
1	4848.5				
1	4851.3				
1	4859.3				
1	4860.7				
1	4867.6				
2	4872.0 c			346.5 = 9×38.5	
2	4877.1 a	228.6 = 6×38.1			
2	4884.3 b		269.1 = 7×38.2		
1	4887.8				
1	4896.4				
1	4910.9 c			307.6 = 8×38.4	
1	4915.1 a	190.6 = 5×38.1			
4	4921.8 b		231.6 = 6×38.6		
4	4925.5				
1	4932.8				
1	4948.4 c			270.1 = 7×38.6	
4	4952.9 a	152.8 = 4×38.2			
2	4955.4				
1	4963.0 b		190.4 = 5×38.1		
1	4966.4				
1	4979.9				
1	4985.5 c			232.9 = 6×38.7	
4	4991.1 a	114.6 = 3×38.2			
2	4993.1				
1	4994.7				
2	4998.1 b		155.3 = 4×38.8		
6	5004.1				
1	5010.2				
1	5016.2				
1	5024.0 c			192.5 = 5×38.7	
2	5030.5 a	75.2 = 2×37.6			
2	5036.1				
6	5038.5 b		114.9 = 3×38.3		
1	5042.3				
1	5045.4				
6	5059.0				
1	5061.4 c			157.1 = 4×39.3	
6	5067.4 a	38.3 = 1×38.3			
2	5076.0 b		77.4 = 2×38.7		
1	5080.3				
2	5083.1				
2	5086.9 d_1				37.4 = 1×37.4
1	5091.7				
1	5101.2 c			117.3 = 3×39.1	
10	5105.7 a				
1	5112.				
6	5123.2				

COPPER EXCITATION—*Continued*

Intensity	Wave-Length	Series *a*. $k=38$	Series *b*. $k=38.4$	Series *c*. $k=38.7$	Series d_1 Series d_2
1	5124.3 d_1				
1	5126.9				
2	5130.5 d_2				
4	5139.9 *c*			$78.6=2\times39.3$	
4	5144.1 *a*	$38.4=1\times38.4$			
10	*5153.4 b*				
2	5163.0 d_1				$38.7=1\times38.7$
1	5168.5 d_2				$38.0=1\times38.0$
4	5179.3 *c*			$39.2=1\times39.2$	
4	5181.8 *a*	$76.1=2\times38$			
4	5183.0				
4	5190.9 *b*		$37.5=1\times37.5$		
8	5192.8				
4	5201.4 d_1				$77.1=2\times38.5$
2	5206.8 d_2				$76.3=2\times38.1$
2	5209.8				
10	*5218.5 c*				
1	5230.9 *b*		$77.5=2\times38.7$		
1	5243.8				
1	5247.5 d_2				$117 \quad =3\times39.0$
6	5256.2 *c*			$37.0=1\times37.5$	
2	5266.2				
2	5269.4 *b*		$116=3\times38.7$		
1	5273.0				
4	5278.5 d_1				$154.2=4\times38.5$
1	5281.3				
1	5284.3 d_2				$154.0=4\times38.4$
4	*5293.0 c*			$74.5=2\times37.2$	
1	5302.6				
1	5307.3 *b*		$153.9=4\times38.5$		
1	5313.2				
1	5322.2 d_2				$191.7=5\times38.3$
1	5326.3				
1	5344.2 *b*		$190.8=5\times38.2$		
1	5352.0				
1	5356.4 d_1				$232.1=6\times38.5$
1	5360.4 d_2				$229.9=6\times38.3$
1	5367.7				
1	5380.8 *b*		$227.4=6\times37.9$		
1	5390.5 d_1				$266.2=7\times38.0$
1	5397.5 d_2				$267.0=7\times38.2$
1	5410.6				
1	5415.5				
1	5431.7				
1	5449.8				
1	5463.4				
1	5470.9				
1	5495.3				
1	5508.7				
1	5529.1				
1	5538.7				
1	5556.5				

It has not been possible to photograph separately the fluorescence produced by each of the three green lines in the copper arc, as even the fluorescence excited by the three lines together was very faint and required a twenty-hour exposure. But, as in the case of magnesium, there was no difficulty picking out the three principal series, *a*, *b*, *c*, one for each exciting line. The arrangement is not very satisfactory, since the spacing is not very constant, and a great many of the strong lines in the spectrum are left outstanding. In addition, a series of doublets d_1 d_2 has been found which may be the series previously observed to be excited by the shortest copper line, λ 5105.7. One or other member of the doublet is lacking in places, so the tables of differences have been calculated from the first complete doublet. This series of doublets is only a secondary series since it does not contain the exciting line as a member. It will be remarked that the wave-length of the exciting line is a mean between the wave-lengths of two members of the series *d*, which may possibly have some significance.

ZINC AND BISMUTH EXCITATIONS

The bismuth arc excites a very brilliant fluorescence, which is entirely due to the blue line λ 4722.7. The resonance spectrum photographed with the 12-foot grating is reproduced on Plate XI, Fig. 6. The fainter lines do not appear in the reproduction and a better idea of the complete spectrum can be had from the chart. Many lines also, which appear single on the print, are in reality close doublets.

In addition to the strong series lines on either side of the exciting line there is a multitude of lines in the yellow-green region. This portion of the spectrum is shown at the bottom of the chart on a scale which is four times larger than that of the upper portion. It resembles closely the resonance spectrum excited by the zinc line λ 4810. The spectrum stimulated by the three blue zinc lines is shown on Plate XI, Fig. 7, and also on the chart. The yellow-green region is of great interest. The two photographs (Figs. 6 and 7) should be compared with the photograph of the fluorescence excited by white light, Fig. 1. The iron lines make it easy to locate the region in which the zinc and bismuth resonance spectra fall. The almost continuous banded spectrum excited by white light, under the micro-

scope is seen to be made up of a multitude of fine lines, ten or more in each one of the flutings. Monochromatic excitation causes the appearance of only a very small percentage of these lines, but they are arranged in a very definite order, as the photographs show. In the bismuth excitation we find a triplet occurring four times at regular intervals, groups of four or five lines being found midway between the triplets. On the chart will be found a drawing of a small portion of the white-light fluorescence spectrum, between the resonance spectra excited by bismuth and zinc. This gives a very good idea of the way in which it is going to be possible to analyze this complicated band spectrum, by a further and more complete study of the resonance spectra.

The wave-lengths of the lines in the bismuth resonance spectrum are given in the following table:

BISMUTH EXCITATION

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
2	4655·7	6	5359·7	8	5441·4
2	4657·6	1	5371·6	7	5442·4
6	4688·9	1	5373·4	8	5446·0
6	4690·0	6	5374·3	6	5447·4
4	4698·5	6	5378·0	6	5456·5
1	4719·9	4	5378·4	4	5457·6
10	4722·7	6	5379·1	6	5459·1
2	4723·0	2	5388·2	4	5462·0
1	4726·7	5	5391·4	4	5463·2
6	4756·4	5	5392·8	2	5469·1
6	4757·3	1	5394 0	6	5469·8
2	4761·0	1	5394·9	4	5470·3
2	4764·5	6	5407·3	6	5472·5
4	4790·6	6	5408·3	6	5473·1
4	4792·8	2	5410·1	6	5474·4
1	5191·0	6	5412·1	6	5480·2
2	5250·3	6	5413·4	6	5480·8
1	5251·0	4	5423·9	6	5489·0
2	5274·8	3	5425·9	6	5490·2
7	5299·8	8	5426·8	6	5491·9
2	5334·3	2	5427·3	6	5501·2
10	5337·7	2	5428·9	6	5504·8
1	5341·1	2	5430·1	2	5520·5
2	5344·4	2	5431·8	2	5521·3
2	5356·6	1	5436·7	4	5531·4
2	5358·1	1	5438·3	8	5552·6

A table of the wave-lengths of the lines excited by zinc will be found in a previous paper.[1]

[1] *Physikalische Zeitschrift*, 9, 450–461, 1908.

The plate reproduced (Fig. 7) will have to be remeasured before a revised table can be published, as some errors have been detected in revising the work.

The close doublets, spaced off at equal intervals and marked *x* on the chart, which appear in the region λ 5100–5300 of the resonance spectrum excited by the zinc arc, are worthy of notice.

As will be seen from the chart the series lines in the blue are close doublets. This may be due to the fact that we are exciting the vapor with a double line (that is, a self-reversed line). The photographs of the absorption spectrum, made by Mr. Clinkscales with the 21-foot grating in the second order, show that the absorption lines are often not more than one-tenth of an Ångström unit apart, consequently a self-reversed line might easily excite two different frequencies. This point requires further investigation.

BLUE-GREEN MAGNETIC ROTATION SPECTRUM

This is shown in coincidence with the white-light fluorescence spectrum on Plate XI, Fig. 2, and in coincidence with the resonance spectrum excited by the zinc arc in Fig. 17. On the new plates 128 lines are shown as compared with 64 lines measured in the previous work. The general result of the new measurements is to emphasize and extend many of the relations which were observed in the first work on the subject. Looking down the list, groups of strong lines will be observed to recur at regular intervals toward the end of the spectrum. Some of these lines were found to be almost coincident with some of the series in the resonance spectra. By comparing these with the magnetic rotation lines, Wood found it possible to arrange many of them into five series, which are numbered from 1 to 5 in the table given on p. 360.

The lines in the blue below λ 4900 become more numerous and irregular in their arrangement; but the series have not been extended into this region as might be done, since we have no corresponding fluorescent series which extend so far. This will be seen by consulting the chart (Plate X) accompanying this paper. As long as we have such a series to guide us in selection we may be sure that the grouping has a physical significance; but when this fails, any further extension of the series can be regarded only as a formal classification.

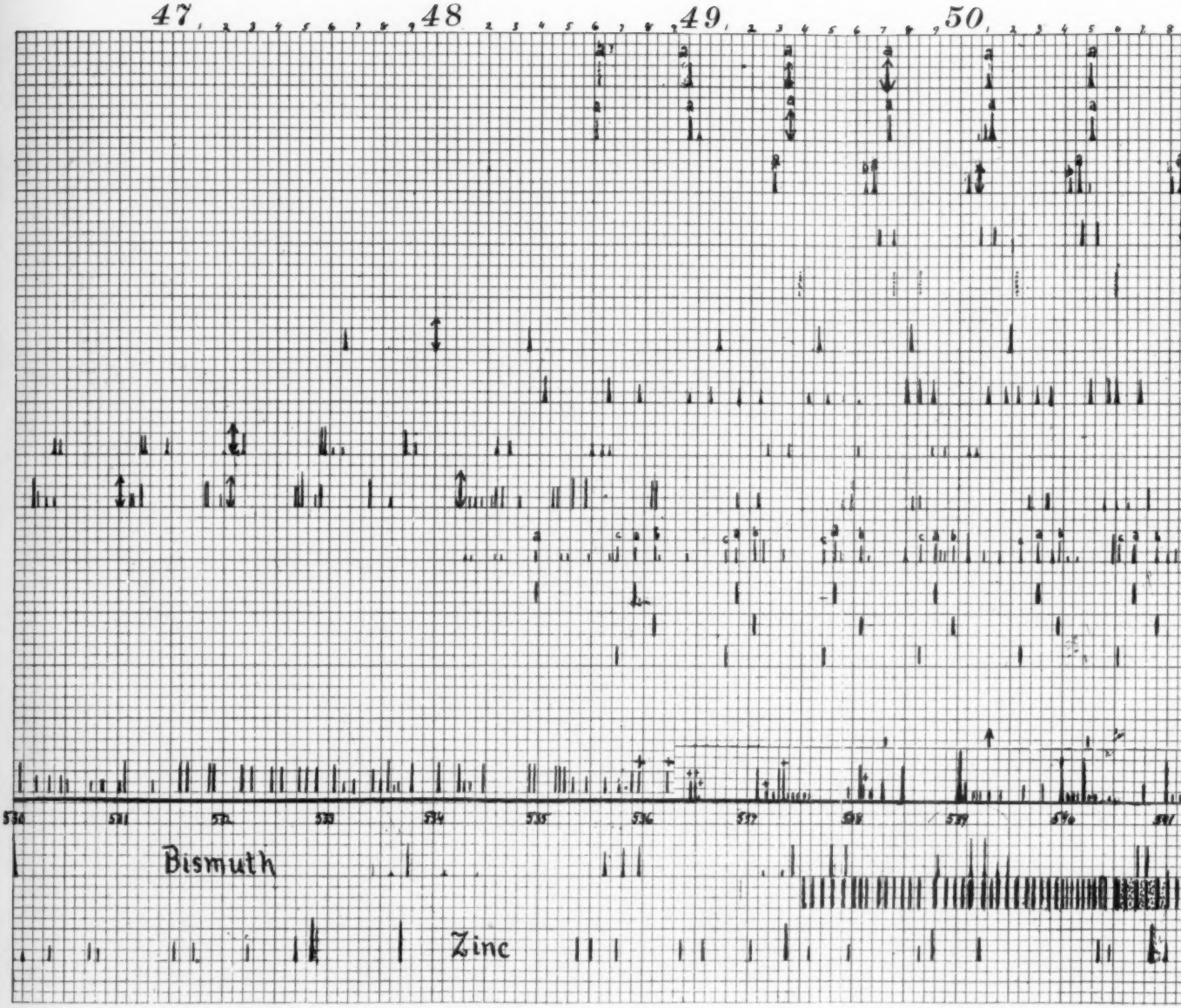
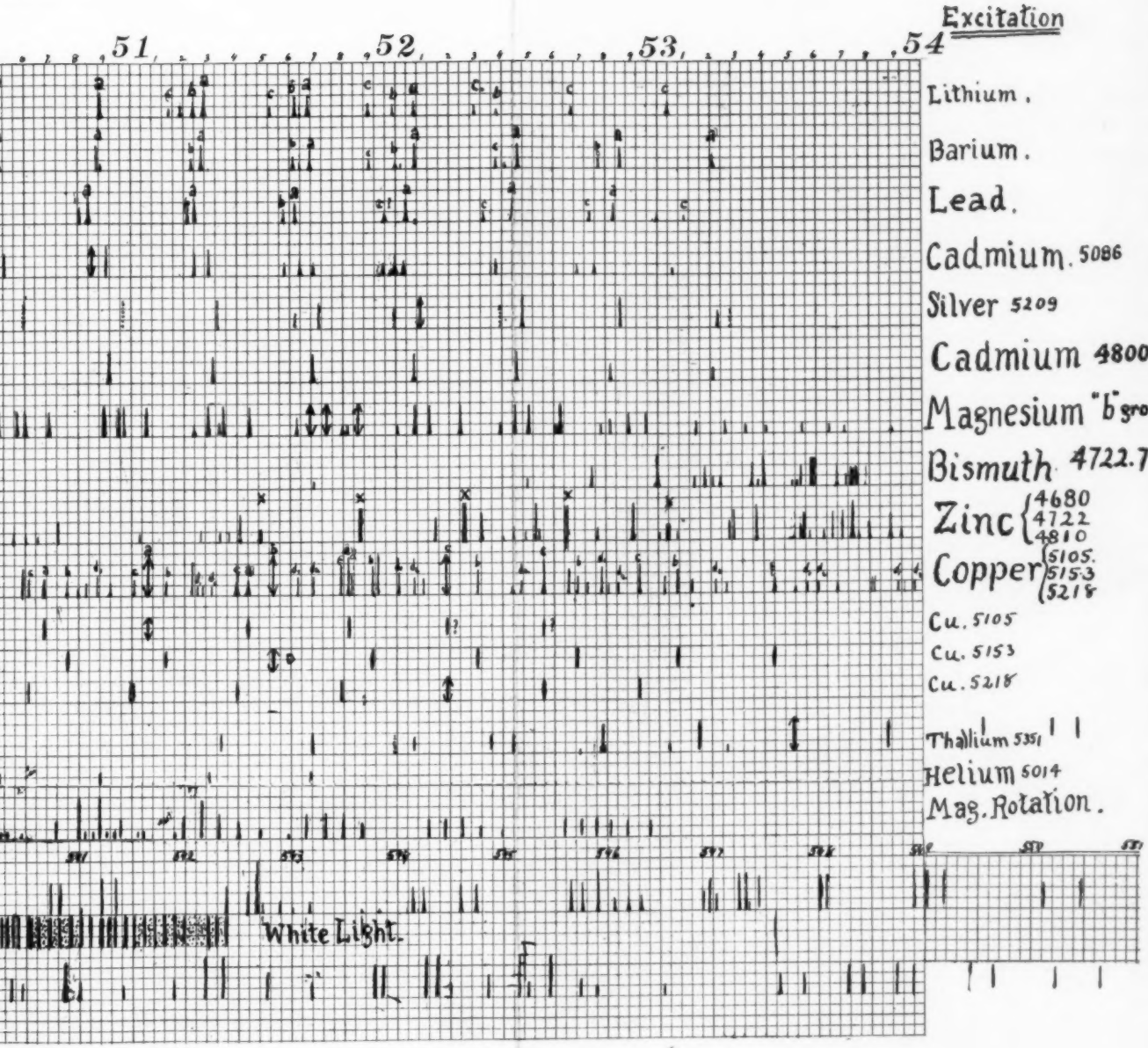


CHART OF RESONANCE AND MAGNET



ND MAGNETIC ROTATION SPECTRA

The most interesting problem in connection with the magnetic rotation is the determination of the direction of rotation of the light in these lines. An attempt was made to study the direction of rotation by means of the Fresnel quartz wedges which gave such beautiful results in the magnetic rotation spectrum in the red, but there was little or no trace of the bright needles of light shooting up or down into the dark interference band (see Plate XI, Fig. 12, for a photograph of this phenomenon in the red). Their failure to appear in the green is due to the smaller angular rotation of the plane of polarization. The problem was finally solved in a different manner for the green spectrum. These wave-lengths in the plane-polarized light passing through sodium vapor along the lines of force in a magnetic field are rotated through a few degrees so that they can pass through a nicol set to extinction for the rest of this region of the spectrum. A small rotation of the nicol in either direction will now brighten up the whole field. In one direction some of the bright lines will still be seen, though less distinctly against the bright background of the rest of the spectrum. Careful observation, however, will show that if the nicol is rotated about four degrees in the opposite direction, these lines disappear. These lines have therefore been rotated about four degrees in this direction by passing through the sodium vapor in the magnetic field. It was observed that the rotation in the brightest lines belonging to the magnetic series was in the same direction as that due to the D lines. The rotation of these lines is therefore presumably due to negative electrons and they have been marked with the negative sign in the third column of the table.

To extend this process to the whole spectrum it was only necessary to take two photographs of the spectrum on the same plate, one in which the nicol was rotated four degrees to the left, and the other in which it was rotated four degrees to the right. These two photographs were totally different, as the bright lines of one were absent in the other. By careful comparison of this plate with the magnetic rotation spectrum, the direction of rotation of all the strong lines could be ascertained at leisure.

All those lines which appeared on the same photograph as the magnetic rotation series and were not visible on the other were therefore rotated in the same direction and have been marked in the

Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum	Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum
2.....			4609	4.....	3		4865.5
2.....			4611.3	4.....		−	4871.5
2.....			4615.8	2.....			4875.1
2.....			4628	4.....		+	4878.2
2.....			4630.6	4.....		+	4889.4
2.....			4634.3	6.....			4892.9
2.....			4636.7	6.....	2?	−	4894.7
2.....			4641.9	6.....		+	4897.9
8.....			4648.9	4.....		+	4899.8
2.....			4653.8	4.....		+	4900.8
2.....			4658.6	6.....	3		4903.3
2.....			4661.2	6.....	4	−	4912.3
2.....			4670.4	10.....	1		4924.4
2.....			4674	2.....		+	4927.3
2.....			4675	10.....	2	−	4932.6
2.....			4681.2	8.....		+	4933.8
2.....			4682.6	2.....			4937.9
10.....		−	4693.7	2.....	3?		4941.6
4.....			4694.6	4.....	5?		4958.5
10.....		−	4703.9	10.....	1	−	4962.5
10.....			4706.5	4.....		+	4964
10.....			4715.4	4.....			4966.8
10.....			4716.9	8.....	2		4971.7
10.....		−	4727.5	10.....	3	−	4979
10.....			4731.4	2.....	4		4985.2
10.....		−	4738.5	10.....	1	−	5001.6
10.....		−	4741.8	6.....	2		5003
10.....		−	4749.3	4.....			5000.3
10.....			4752.1	4.....			5007.2
10.....			4756.6	4.....			5008.2
10.....			4762.7	4.....			5009.4
10.....			4766.7	4.....			5012.7
4.....		−	4769.8	4.....	3		5017.5
4.....			4777.1	5.....	4		5025.1
4.....			4780.4	5.....	5		5033.3
10.....		−	4782.8	9.....	1	−	5040.2
2.....		−	4784.9	4.....			5044.2
1.....			4786.8	4.....			5045.7
2.....			4787.5	8.....	2		5048.3
1.....			4789.5	4.....			5049.4
10.....		−	4792.4	4.....		−	5052.6
10.....		−	4802.2	4.....	3		5058.4
10.....			4809.9	8.....	5		5071.8
4.....		−	4812.2	8.....	1	−	5079.9
4.....			4814.5	8.....	2	−	5087.4
10.....			4819	8.....	3		5094.8
10.....			4837.3	2.....			5097.5
4.....		−	4839	4.....			5102.3
4.....		−	4846.8	2.....			5115.8
4.....			4848.4	8.....	1	−	5119.1
4.....			4850	8.....	2	−	5126.3
4.....			4852.7	8.....	3	−	5133.3
4.....			4858.3	8.....	4		5140.8

Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum	Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum
8.....			5148.8	1.....			5228.3
6.....			5159.1	1.....	1?		5232.2
8.....	2	−	5165.8	4.....			5238.9
8.....	3	−	5173.1	2.....			5243
8.....	4		5179.6	6.....	5?		5263.8
8.....	5		5186.5	6.....	1?		5270.3
8.....			5192.3	6.....	2?		5276.6
8.....	3		5212.1	6.....	3?		5282.6
8.....	4		5218.3	6.....	4?		5288.6
8.....	5		5225.4	6.....			5298.9

table in the same way. There were some lines which appeared only on the photograph in which the series were absent, and so were rotated in the opposite direction. These have been provisionally assumed to be due to positive electrons and are marked with the positive sign in the table.

These lines are nearly all below λ 4900, and though a formal grouping is possible, it has not been considered worth while to make any assignment of them into series until it has been ascertained if there are any fluorescent lines corresponding to them.

The magnetic rotation lines are shown on the chart.

WHITE-LIGHT FLUORESCENCE

There is a very interesting connection between the white-light fluorescence and the magnetic rotation. In the photograph obtained with the grating, the fluorescence in the green extends from λ 4700–λ 5500, its brightest region being from λ 5000–λ 5500. Below this the spectrum is weak and contains a great number of fine lines among which there is a very irregular distribution of intensity. Beyond λ 5000 we have a well-defined system of bands. On examining them with an eyepiece these bands are found to consist of a great number of fine lines (see Fig. 4 at point indicated by arrow). On the violet edge of each band there is a narrow region about two Ångström units wide, in which there is no fluorescence at all, or it is a minimum. If the photograph of the magnetic rotation spectra be superposed, the lines will be found to coincide with these dark spaces. It will be seen from the table given below that the magnetic rotation

lines are usually about 1 Å. U. shorter so that they are always on the violet side of the bright lines in the fluorescence. The measurements of the wave-lengths of the heads of the bands can be considered only approximate, but they serve for the purposes of comparison. A complete table of these is given first and then a table of those lines in the two spectra which correspond.

On account of this correspondence between the two spectra it is possible to arrange the fluorescent bands in series which are in step

WHITE-LIGHT FLUORESCENCE

Wave-Length	Wave-Length	Wave-Length	Wave-Length	Wave-Length	Wave-Length	Wave-Length
5026.1	5126.5	5203.4	5277.1	5323	5392.1	5453.3
5034.1	5133.2	5210.1	5283.2	5338.7	5397.4	5458.2
5041	5141.2	5216.6	5289.7	5345	5417.2	5476
5049	5148.3	5232.5	5296	5351.2	5422.2	5481
5050.2	5159.7	5238.3	5302.9	5364.2	5427.2	5485.9
5072.1	5166	5245.6	5308.6	5369.4	5431.3	5490.5
5081	5173.1	5249.1	5314.8	5375.4	5436.8	5496
5088.4	5180.1	5254.6	5320.8	5381	5443.2	5500.4
5095.4	5186.9	5264.1	5326.8	5386.4	5448.2	5505.3
5119.6	5193.8	5270.6				

WHITE-LIGHT FLUORESCENCE AND MAGNETIC ROTATION SERIES

Series	White-Light Fluorescence	Magnetic Rotation	Series	White-Light Fluorescence	Magnetic Rotation
4.....	5026.1	5025.1	3.....	5173.1	5172.9
5.....	5034.1	5033.3	4.....	5180.1	5179.6
1.....	5041	5040.2	5.....	5186.9	5186.5
2.....	5050.2	5048.3	1.....	5193.8	5192.3
5.....	5072.1	5071.8	1?.....	5232.5	5232.2
1.....	5081	5079.9	2?.....	5238.3	5238.9
2.....	5088.4	5087.4	3?.....	5245.6	5243
3.....	5095.4	5094.8	4?.....	5249.1	
1.....	5119.6	5119.1	5?.....	5264.1	5263.8
2.....	5126.5	5126.3	1?.....	5270.6	5270.3
3.....	5133.2	5133.3	2?.....	5277.1	5276.6
4.....	5141.1	5140.8	3?.....	5283.2	5282.6
5.....	5148.3	5148	4?.....	5289.7	5288.6
1.....	5159.7	5159.1	5?.....	5296.0	
2.....	5166	5165.8			

with the magnetic rotation series and also with the resonance series. This is illustrated by the chart. The series apparently becomes disorganized after the termination of the magnetic rotation and cannot be carried farther. Beyond this new bands appear and though

there seems to be some regular arrangement it is different in kind. It must be studied in conjunction with the resonance spectra in the same region excited by the zinc and bismuth arcs. As a result of the regular grouping between λ 4900 and λ 5300 the white-light fluorescence can be almost entirely represented by a system of five bands which recur at regular intervals along the spectrum. According to the scheme developed at the close of the paper each of these bands is due to one vibrating system and the whole five bands are interconnected. The great regularity found in the resonance spectra in this region falls in with this scheme.

THE RESONANCE AND MAGNETIC ROTATION SPECTRA IN THE ORANGE AND RED REGION

The red region of the fluorescence spectrum excited by white light appears nearly continuous. Occasionally faint traces of bands can be seen if the vapor density is just right and the illumination is very intense.

The magnetic rotation bright-line spectrum is, however, much brighter than in the blue-green region and quite as discontinuous. A portion of it (about $\frac{1}{2}$) is shown on Plate XI, Fig. 15. On this plate the iron comparison spectrum below is quite faint. Immediately above (Fig. 12) will be seen one of the plates from which the direction of rotation of each line was determined by the method described in an earlier paper. The dark band running horizontally through the center of the spectrum is caused by the failure of the nicol prism to transmit the horizontally polarized light in the region. Immediately above and below this line, the light in the spectrum is polarized vertically and is consequently passed by the nicol. This "distribution of polarization" is accomplished by the double Fresnel wedge of dextro- and laevo-rotatory quartz. The absorption lines of the sodium vapor are beautifully shown. When the vapor is magnetized the wave-lengths which are rotated by the vapor are shown by needles of light which shoot up or down into the horizontal dark line according to the direction of the rotation.

The wave-lengths of the lines in the red magnetic rotation spectrum are given in the following table. There are over 340 in all, or two and a half times as many as in the green-blue spectrum.

RED MAGNETIC ROTATION SPECTRUM

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
2	5943.8	2	6150.0	4	6315.4
2	5945.0	1	6159.1	2	6317.1
2	5945.2	8	6163.1	2	6318.4
2	5958.1	2	6164.6	6	6320.6
3	5963.1	4	6165.9	2	6321.7
3	5966.8	4	6167.5	8	6323.8
3	5970.0	4	6170.1	8	6324.2
3	5974.0	6	6171.8	8	6325.5
3	5975.5	2	6172.9	2	6327.1
4	5995.4	8	6179.3	6	6334.5
2	5997.5	6	6181.4	2	6335.5
4	5998.9	2	6183.1	2	6338.9
4	6005.3	8	6184.2	2	6341.9
2	6007.0	1	6191.7	2	6344.3
4	6007.6	4	6196.8	4	6347.0
4	6012.9	8	6197.4	4	6351.2
4	6019.0	6	6198.1	4	6351.7
4	6020.0	6	6199.1	2	6353.9
4	6022.8	2	6204.6	2	6356.2
4	6024.2	2	6206.4	4	6358.6
4	6027.3	6	6210.4	2	6360.3
2	6029.0	4	6214.2	4	6364.8
4	6029.8	8	6215.6	6	6366.8
2	6030.7	6	6218.5	4	6368.8
4	6031.6	2	6221.6	2	6371.7
1	6037.2	2	6222.4	10	6373.5
1	6045.7	2	6225.7	4	6374.4
1	6049.5	4	6227.2	4	6376.2
1	6053.6	6	6229.6	6	6378.2
1	6062.8	8	6230.9	8	6379.3
6	6063.4	6	6236.4	2	6384.2
4	6069.3	6	6239.9	8	6385.9
2	6070.3	2	6251.3	8	6386.6
6	6071.4	6	6253.2	4	6388.5
4	6075.9	4	6255.2	8	6400.2
4	6076.6	8	6256.1	1	6402.3
2	6078.9	1	6257.4	4	6406.5
2	6080.5	4	6259.5	6	6407.0
1	6084.8	6	6259.6	2	6412.7
6	6086.3	8	6262.6	10	6420.1
2	6087.8	2	6266.5	4	6420.8
2	6090.9	4	6270.8	1	6422.1
4	6092.5	8	6273.2	4	6422.9
6	6107.6	2	6276.0	2	6424.0
8	6109.1	4	6276.9	10	6427.2
6	6112.7	4	6279.0	4	6429.3
6	6113.8	4	6285.3	10	6434.9
6	6120.8	8	6288.1	2	6437.8
8	6126.0	4	6290.3	4	6438.5
1	6133.5	7	6301.7	4	6440.3
1	6134.2	1	6308.4	4	6442.5
7	6139.2	2	6309.7	1	6444.0
6	6141.1	2	6312.1	8	6445.9
4	6143.6	8	6313.6	10	6449.8
4	6147.5	6	6314.4	4	6450.5

RED MAGNETIC ROTATION SPECTRUM—*Continued*

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
4	6451.3	2	6596.3	4	6810.8
2	6452.1	4	6600.9	4	6811.8
4	6458.1	8	6610.3	4	6815.2
2	6459.3	4	6613.4	2	6817.2
4	6462.8	2	6616.5	2	6818.3
2	6468.7	2	6617.7	2	6823.9
4	6470.5	2	6618.7	4	6833.0
2	6470.9	1	6621.5	4	6840.0
2	6472.1	2	6622.9	1	6864.7
4	6477.3	8	6624.2	2	6866.7
4	6478.0	6	6625.2	2	6869.8
4	6479.2	4	6626.2	1	6871.2
4	6480.0	1	6632.1	1	6872.6
4	6481.5	1	6635.4	8	6875.8
8	6481.8	1	6636.5	1	6877.4
8	6482.7	1	6641.0	1	6878.7
4	6483.6	6	6646.6	1	6880.9
4	6484.4	1	6657.5	1	6882.0
2	6485.4	4	6663.4	8	6885.8
4	6486.7	4	6664.4	4	6887.0
4	6487.7	1	6666.6	4	6889.4
6	6487.9	4	6668.2	4	6890.5
8	6490.1	1	6674.2	2	6904.1
8	6490.9	4	6675.7	2	6905.1
4	6494.8	6	6677.3	1	6933.5
2	6493.3	6	6678.9	1	6935.3
6	6502.4	2	6684.1	1	6936.9
4	6503.0	2	6685.8	1	6938.5
4	6504.6	4	6690.2	2	6941.1
2	6505.7	8	6692.9	2	6943.7
4	6510.1	1	6698.2	2	6945.2
2	6513.3	2	6704.6	6	6946.7
6	6515.0	1	6711.2	4	6948.1
6	6515.8	1	6714.3	4	6949.6
2	6516.9	1	6715.2	2	6952.9
1	6524.7	1	6727.0	2	6956.8
4	6532.4	2	6730.5	4	6958.1
2	6538.6	4	6734.4	8	6959.6
2	6544.1	4	6737.9	4	6961.0
10	6548.4	4	6739.1	4	6962.5
4	6549.9	6	6741.4	2	6964.2
4	6553.4	6	6746.7	2	6965.5
1	6554.6	2	6750.9	4	7008.5
4	6555.5	1	6754.1	4	7009.7
8	6557.1	1	6757.9	2	7016.1
8	6557.4	6	6761.9	4	7018.9
2	6558.4	6	6763.0	4	7020.0
1	6560.3	4	6767.1	8	7021.6
1	6561.5	2	6780.5	4	7022.6
4	6565.3	1	6793.8	4	7024.1
2	6567.4	4	6796.1	4	7028.2
2	6570.9	6	6803.5	4	7029.2
2	6573.6	6	6805.8	1	7031.6
3	6576.9	6	6806.7	2	7033.0
8	6580.3	4	6810.1	8	7034.7

RED MAGNETIC ROTATION SPECTRUM—*Continued*

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
4.....	7036.2	4.....	7098.8	2.....	7111.9
4.....	7037.8	4.....	7103.8	2.....	7113.8
2.....	7095.8	2.....	7109.1	2.....	7115.3
4.....	7097.3	4.....	7110.5		

Following this table is a classification of the lines according to the direction of rotation. The amounts of rotation, i. e., the distances to which the needle of light penetrates, is roughly indicated by numerals.

NEGATIVE MAGNETIC ROTATION LINES (λ 6000–λ 7000)

Intensity	Rotation	Wave-Length	Intensity	Rotation	Wave-Length	Intensity	Rotation	Wave-Length
2	4	5997.5	8	2	6262.8	2	6	6468.7
4	4	6019.0	4	2	6270.8	4	6	6477.3
4	2	6027.3	8	6	6273.2	4	7	6478.0
2	2	6030.7	2	6	6276.0	4	7	6479.2
1	4	6037.2	4	4	6279.0	4	8	6480.0
1	2	6045.7	8	2	6288.1	4	8	6481.5
6	2	6063.4	7	4	6301.7	8	10	6481.8
6	6	6071.4	8	10	6313.6	8	8	6482.7
4	8	6075.9	6	8	6314.4	8	10	6502.4
2	4	6084.8	2	6	6318.4	6	8	6503.0
1	1	6085.5	2	4	6335.5	4	4	6510.1
4	4	6092.5	2	4	6341.9	10	10	6548.4
6	4	6107.6	2	4	6344.3	1	8	6561.5
8	8	6126.0	6	4	6366.8	2	4	6573.6
6	4	6141.1	4	4	6368.8	8	10	6610.3
4	2	6147.5	2	4	6371.7	4	4	6626.2
2	2	6150.0	10	10	6373.5	4	8	6663.4
4	4	6167.5	6	4	6378.2	6	10	6678.9
4	4	6170.1	4	1	6388.5	2	6	6685.0
2	4	6172.9	8	10	6400.2	2	6	6698.2
8	4	6179.3	4	10	6406.5	4	6	6734.4
6	4	6181.4	6	10	6407.0	6	10	6746.7
8	10	6184.2	10	10	6420.1	2	2	6750.9
2	2	6204.6	4	8	6429.3	6	8	6803.5
6	2	6210.4	10	10	6434.9	6	8	6806.7
6	6	6218.5	2	4	6437.8	4	8	6889.4
8	8	6230.9	8	4	6445.9	4	8	6890.5
6	6	6236.4	4	8	6450.5	4	8	6949.6
6	4	6239.9	4	10	6451.3	4	2	7018.9
4	4	6253.2	4	6	6462.8	8	2	7021.6
8	4	6256.1						

POSITIVE MAGNETIC ROTATION LINES (λ 6000–λ 7200)

Intensity	Rotation	Wave-Length	Intensity	Rotation	Wave-Length
8	4	6109.1	4	4	6532.4
8	4	6126.0	8	10	6551.1
7	8	6139.2	8	10	6557.4
6	8	6199.1	8	6	6580.3
8	8	6215.6	4	10	6613.4
6	6	6259.6	8	10	6624.2
4	6	6315.4	4	4	6664.4
8	10	6323.8	6	10	6677.3
8	10	6324.2	8	10	6692.9
8	10	6325.5	4	4	6737.9
4	4	6351.2	6	10	6761.9
4	4	6358.6	6	4	6763.0
8	6	6379.3	6	4	6806.7
8	10	6385.9	4	4	6810.1
8	10	6386.6	4	4	6810.8
4	6	6388.5	4	8	6840.0
6	6	6407.0	8	4	6875.8
4	6	6422.9	8	6	6885.8
10	10	6427.2	4	6	6887.0
4	4	6442.5	4	4	6946.7
10	10	6449.8	4	10	6959.6
2	4	6470.9	8	4	7008.5
4	8	6486.7	8	6	7021.6
8	10	6490.1	8	4	7034.7
8	10	6490.9	4	6	7047.8
6	8	6502.4	4	6	7111.9
6	6	6515.0	2	6	7115.3
6	6	6515.8			

LITHIUM EXCITATION IN THE RED

The red resonance spectrum excited by the lithium lines λ 6104 and 6708 has been photographed only with a small two-prism spectrograph (Fig. 5). The wave-lengths can be considered accurate only to within 2 or 3 Å. U. The series-difference k is nearly twice as large as in the green-blue region; $k=54$ and $k=63$ for the two series.

By comparing the magnetic rotation spectrum with the lithium resonance spectrum, two series have been found in the table of positively rotated lines with spacings of 63 and 67. These series include all of the strong lines. The negative lines do not yield themselves so readily to arrangement in series and nothing has yet been done with them.

The wave-lengths of the red resonance lines, and the table of the series in the positive magnetic rotation spectrum follow.

LITHIUM EXCITATION (λ 5800–7100)

Wave-Length	Series *a*. $k=54$ Series *b*. $k=63$
5896 *a*	$206=4\times52$
5942 *a*	$160=3\times53$
5998 *a*	$104=2\times52$
6047 *a*	$55=1\times55$
6102	
6158 *a*	$56=1\times56$
6218 *a*	$116=2\times58$
6277 *b*	$431=7\times62$
6338 *b*	$370=6\times62$
6396 *b*	$312=5\times62$
6461 *b*	$247=4\times62$
6519 *b*	$189=3\times63$
6580 *b*	$128=2\times64$
6643 *b*	$65=1\times65$
6708	
6772 *b*	$64=1\times64$
6834 *b*	$126=2\times63$
6898 *b*	$190=3\times63$
6965 *b*	$257=4\times64$
7015 *b*	$307=5\times62$
7074 *b*	$366=6\times61$

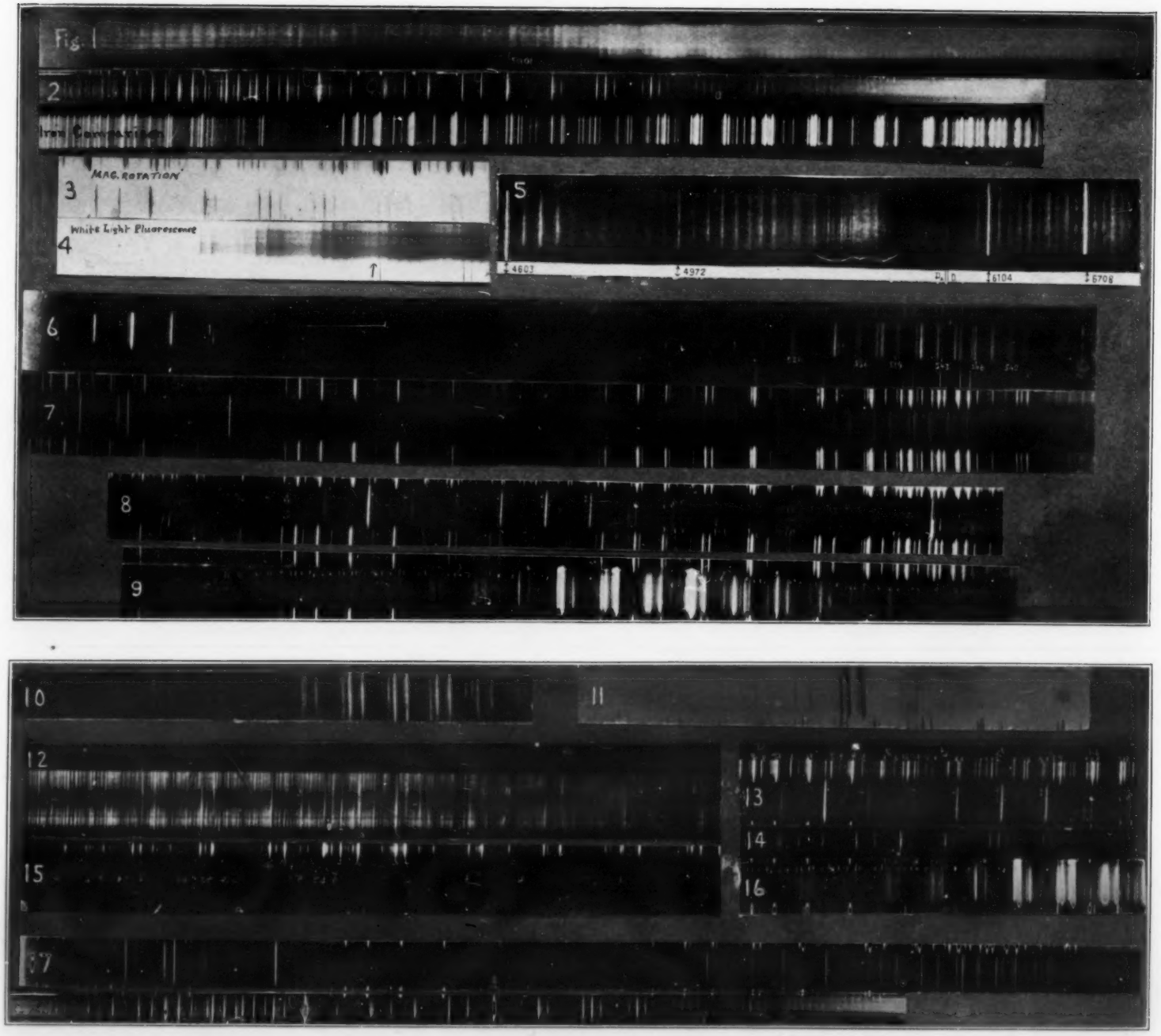
SERIES IN THE POSITIVE MAGNETIC ROTATION (λ 6000–λ 7200)

Intensity	Rotation	Wave-Length	Series Differences
7	8	6139.2	$310.6=5\times62.1$
6	8	6199.1	$250.7=4\times62.7$
6	6	6259.6	$190.2=3\times63.4$
8	10	6323.8	$126.6=2\times63.3$
8	10	6324.5	$125.6=2\times62.8$
8	10	6325.5	$124.3=2\times62.1$
10	10	6449.8	
6	6	6515.0	$65.2=1\times65.2$
6	6	6515.8	$66.0=1\times66.0$
8	6	6580.3	$131.5=2\times65.0$
10	10	6427.2	
8	10	6490.1	$62.9=1\times62.9$
8	10	6490.9	$63.7=1\times63.7$
8	10	6557.1	$129.9=2\times65.0$
8	10	6557.4	$130.2=2\times65.1$
8	10	6624.2	$197.0=3\times65.7$
8	10	6692.9	$265.7=4\times66.4$
6	10	6761.9	$334.7=5\times67.7$

SUMMARY

We are now in a position to summarize the results of the analyses of all these different spectra and see what general conclusions can be drawn regarding the nature of the vibrating system which gives the

PLATE XI



RESONANCE AND MAGNETIC ROTATION SPECTRA OF SODIUM VAPOR

fluorescence in the region examined. The following table (p. 371) is both a compendium of all the properties of the different series which have been discussed and a numerical guide to the chart of resonance spectra. Nearly all the series have a line between λ 5140–λ 5190 which has been taken as a typical line of the series, and determined the order in which they have been arranged. For convenience the magnetic rotation series have been denoted by *M* and the white-light fluorescence series by *F*. The stimulations due to zinc, bismuth, thallium, and the shorter cadmium line have not been discussed. Except in the case of thallium the resonance spectra produced usually consists of a fairly regular group in the violet and a complicated spectrum in the yellow-green which in no case has been satisfactorily arranged in series with some lines in the intervening region. The green thallium line λ 5350 gives a series from λ 5200 to λ 5400 in which the lines are about 37 Å. U. apart. But as all these resonance spectra seem to be radically different from the other resonance spectra already described they are omitted from the present discussion.

It might appear that in the case of the more complicated spectra there was a certain arbitrariness in picking out the lines which belong together. There is no question about the series-grouping in silver, lead, or lithium excitations. These series can be used to check the arrangement of the magnetic rotation lines. The latter, in turn, aid us in picking out new series in more complex spectra, such as in the magnesium and copper excitations. It rarely happened that there was a choice between two lines. If there was, the one which gave the best value for the common difference was adopted. By this mode of classification each series acts as a check on the others and they probably in all cases do represent lines which are physically related. Upward of 200 lines have been obtained in the resonance spectra described above and of these almost two-thirds have been classified into series.

It was somewhat of a disappointment to find that even with the new measurements the common difference k is not an absolute constant. The divergencies from a constant value are not systematic. It is possible they may to a certain extent, not exceeding 0.5 Å. U., be accounted for by errors of observation in the case of faint lines. Most of the lines whose relative intensity is marked "2" were so

faint that they were barely visible under the microscope of the dividing engine, but even making allowance for this source of error the discrepancies, in some cases, are too large to disappear entirely as in the case of the magnesium and copper series. Since these departures from the law of equi-spacing are not systematic they cannot arise from the fact that this law is an approximation but they must be in the nature of disturbances. In fact it would be surprising if such a complicated vibrating system as we must have here could emit radiations whose wave-lengths would be exactly represented by such a simple law. Slight apparent shifts may also arise from the presence of a strong absorption line, for the fluorescent light is obliged to pass through cooler sodium vapor on its way to the spectroscope, as has been pointed out in an earlier paper.

The dynamical model of the sodium fluorescence proposed by Stephenson suggests that the differences of the frequencies of the lines in the same series should be constant. But a simple trial for such a series as silver *a* proves immediately that this relation does not hold. The variations are very much greater than before. We conclude therefore that the formula which most nearly represents the lines in a series is

$$n=\frac{1}{\lambda}=\frac{1}{\lambda_0+xk}=\frac{k}{\lambda_0/k+x}=\frac{No}{u+m}$$

There is an obvious resemblance to the ordinary formula for spectrum series.

Though we cannot accept the dynamical model suggested by Stephenson, still it is an interesting analogy. It is probable that the series are due to some cyclic electromagnetic system such as a ring of electrons in orbital motions, and that the differences of the wave-lengths in the series bear some relation to the period of the cyclic motion.

Even the average value of k for each series is not a constant, as will be seen from the table, in which it varies from 38–39. The different series should therefore get slightly out of step when they are plotted on the chart, but the effect is not noticeable. The difference in the value of k is because the series only coincides for a small part of the spectrum; and the differences have been taken over different parts of the spectrum and from a different origin in each case. Where

two series have corresponding members at any point they will be found to remain very closely in step with each other all along the spectrum until one series disappears. We say therefore that all these series approximate to an ideal type in which the spacing is uniform for every series.

Series	k	No. of Lines	Exciting Line	Typical Line	First Line	Last Line
M 5				5148		
F 5				5148.3		
Lithium	*c* 37.5	6	4972.1	5152.8	5192.8	5303.3
Copper	*b* 38.4	9	5153.4	5153.4	4885.8	5230.9
Lead	*b* 39	6	5006.5	5158.5	4964.4	5158.5
Cadmium	*d*	4	5086	5159		
M 1				5159.1		
F 1				5159.7		
Silver	*b* 38	4	5209.2	5160	5122	5236
Barium	*b* 38.3	6	4932	5161.6	5123.9	5318.5
Lead	*a* 39	10	5006.5	5162.4	4929.4	5278.8
Lithium	*b* 38.4	2	4972.1	5162.4	5124	5162.4
Copper	d_1 38.4	5	5105.7	5163	5086.7	5279.2
Cadmium	*b*	7	5086	5164.4		
M 2				5165.8		
F 2				5166		
Lithium	*a* 38.7	7	4972	5167.3	4934.5	5167.5
Magnesium	*a* 38.9	9	5167.5	5167.5	5050	5244
Barium	*a* 38.3	12	4934	5167.8	4860.9	5321.3
Copper	d_2 38.5	6	5105.7	5168.5	5130.5	5322.2
Cadmium	*c*	6	5086.2	5169.5		
Silver	*a* 38.3	11	5209.2	5170.8	4947.5	5324.5
Magnesium	*b* 38.5	12	5172.9	5172.9	4865.8	5249.2
M 2				5172.9		
F 3				5173.1		
Copper	*c* 38.4	7	5218.5	5179.3	4873.8	5256.2
M 4				5179.6		
F 4				5180.1		
Copper	*a* 38.1	9	5105.7	5181.8	4878.9	5181.8
Magnesium	*c* 38.1	5	5183.8	5183.8	4842.3	5300.8
M 5				5186.5		
F 5				5186.9		

An attempt has been made to group all these series into one comprehensive scheme. The arrangement of the resonance spectra into series has an intimate connection with the regularity which has already been noticed in the spectra of the white-light fluorescence and magnetic rotation in the same region (λ 4900–λ 5300). In this interval we find that both spectra consist of five series of lines and bands respectively, in step with the resonance spectra. If we assume that the series are due to the forced oscillations of a cyclic system, then

the lines in each band would correspond to the different frequencies of the system, each of which gives an equally spaced series, so that the band would recur at equal intervals along the spectrum, which depend on the period of the cyclic motion. If we take the table of all the series, we see that, on this scheme, the series lithium *c*, copper *b*, lead *b*, and cadmium *d* all belong to the band which corresponds to the fifth magnetic series, and so on for the other series.

This fluorescent band should be the complement of the corresponding portion of the absorption spectrum. We do not, however, observe any periodicity in the absorption spectrum of sodium vapor in vacuo, but at atmospheric pressure the spectrum becomes fluted and these flutings correspond exactly to the white-light fluorescent bands. They are produced by the increase of the absorption in that part of the spectrum which corresponds to the head of the fluorescent band.

This phenomenon is no doubt connected with the magnetic rotation which takes place only at the head or tail of a band. It has been shown that the magnetic rotation in the lines which are members of any of the magnetic series is in the same sense as at the D lines, which are due to negative electrons. It would, however, be an unwarranted extension of elementary theory to assert that the fluorescent lines are all due to negative electrons, but it is probable that they are.

If we make the assumption that each band corresponds to one vibrating system we must assume that the different bands are interconnected; for a monochromatic stimulation sets two and even three series going which are each in different bands. This will be seen from the chart or the table. The lithium and barium excitations are good examples of this. They excite three series, *a* in the second band, *b* in the first band, *c* in the fifth band. In the detailed discussion it was shown that these two resonance spectra were very similar and were doubtless due to the same system or combination of systems.

This is the only experimental connection which has been observed between the series. The hypothesis that the lines in one band belong to the same system is questionable. But the economy of thought attained by the representation of the phenomena by the above scheme makes it worthy of consideration.

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TWO CURIOUSLY SIMILAR SPECTROSCOPIC BINARIES

By J. S. PLASKETT and W. E. HARPER

The orbit of the spectroscopic binary *ι Orionis* was published by the authors of this paper more than a year ago[1] and later a least-squares correction was added by Mr. Plaskett.[2] Owing to the very diffuse lines of its spectrum the question of a secondary effect in its orbit was left unsettled. Recently the undoubted presence of a secondary disturbance in the strikingly similar orbit of the star *B. D.* −1°1004 obtained by Mr. Harper seemed to justify a redetermination by Mr. Plaskett of the elements of the former, adding terms for a secondary effect.

On account of the disconnected character of the investigation it has seemed the most logical plan to discuss these two binaries following the order of development of the work.

ι Orionis

For the sake of completeness a short résumé of the published work on this star will be given. *ι Orionis*, R. A. $5^h\ 30^m.5$, Dec. −5° 59′, type Ib, photographic magnitude 3.4, was discovered and announced by Frost and Adams[3] as a spectroscopic binary in 1903. It was under observation here from December 11, 1906, to January 25, 1908, and 107 plates were used in obtaining the orbit. Considerable uncertainty attaches to the measurements on account of the broad, diffuse, and frequently asymmetric character of the lines and their low intensity. This is indicated by the high probable error, about 7 km, of a single plate. The elements as determined graphically and twice corrected by least squares are as follows:

ELEMENTS OF *ι Orionis*

Element	Graphical	1st Solution	2nd Solution
K	112.0	109.92	109.90 km
e	0.75	0.7552	0.7543
ω	110°	113°.31	113°.28
T	*J. D.* 2,417,587.94	7,587.991	7,587.993
γ	+20.7	+21.34	+21.34 km
U	29.136	29.136	29.136 days
$a \sin i$	29,680,000	28,867,000	28,709,000 km

[1] *Astrophysical Journal*, **27**, 272, 1908.

[2] *Ibid.*, **28**, 274, 1908.

[3] *Ibid.*, **18**, 383, 1903.

As mentioned in the original paper a secondary effect of some kind is probably present, although its probability is somewhat diminished by the least-squares solutions. Owing to the inferior accuracy of the measures it was not further considered until the striking resemblance between its orbit and that of *B. D.* −1°.1004 obtained by Mr. Harper led to a redetermination of the elements including terms for a secondary effect.

B. D. −1°.1004

($\alpha = 5^h\,36^m$; $\delta = -1°\,11'$; Mag. = 5.1; Spectral type Ib)

Four plates of this star, one in 1905 and three in 1906, were made at the Yerkes Observatory and the results showed it to be of varying radial velocity. It was accordingly announced as a spectroscopic binary by Professor Frost,[1] who made mention that the helium line λ 4388 gave a distinctly different displacement from the other lines; other than that there was no evidence of the existence of a second component spectrum.

Work was commenced on the star here December 28, 1907, and up to March 31, 1909, thirty-six spectrograms had been secured. The instrument used was the single-prism spectrograph which at $H\gamma$ has a dispersion of 30.2 tenth-meters per millimeter. The spectrum is of the helium type and the lines are fairly well adapted for measurement. The following table gives the more important lines used:

LINES IN B. D. −1°.1004

Element	Wave-Length	Element	Wave-Length
H	4861.527	*H*	4340.634
He	4713.308	*Fe*	4325.939
Fe	4549.642	*C*	4267.301
Fe	4528.798	*He*	4143.919
Mg	4481.400	*He*	4121.016
He	4471.676	*H*	4101.890
He	4437.718	*He*	4026.352
He	4388.100	*H*	3970.177

Of these the lines most commonly used were those of hydrogen and helium, along with the carbon line λ 4267. The iron lines were only visible when the spectrum was not too dense: a plate having the best exposure for the hydrogen and helium lines was usually too

[1] *Astrophysical Journal*, **23**, 264, 1906.

dense to show up the iron lines. The latter, when measured, however, showed no difference in displacement to the others, nor did the helium line, λ 4388, which Frost commented upon. Evidently in our plates the spectrum of one component only appeared.

Early in 1908 the period and general form of the oscillation-curve were known. It was seen that there was a rapidly descending branch of the curve where it would be well to have as many observations as possible and it was especially watched for at these critical times. Unfavorable weather, however, during the season of 1908–1909 prevented any observations being secured at the time of maximum negative velocity; otherwise the curve is fairly complete.

In determining the period much assistance was given by the early observations of Frost. While our own results gave a period slightly over 27 days, the fact that an interval of some thirty or forty periods had elapsed between the Yerkes results and our own made it possible to determine the period with greater precision. One of the early observations fell at the maximum of the curve and the period determined by using this observation along with our own maxima was 27.160 days, which cannot be in error much more than 5 in the last place.

Using this period, the phases of the thirty-six observations from an arbitrary epoch were now computed. They were then grouped into fourteen normal places, weights being assigned to each group depending not only upon the sum of the weights of the individual plates but also upon the number of nights involved. When an attempt was made to obtain preliminary values of the elements by the graphical method of Dr. W. F. King[1] it was found that no curve derived from simple elliptic motion would suit the observations; there was a secondary disturbance of some nature whose period was coincident with the period of the star itself. Secondary disturbances in other binaries—one of one-half the period, another of one-third the period—have recently been found in our work here, the assumption of their presence greatly improving the agreement between theory and observation. Hence no simple solution was attempted. After a great many trials a set of elements was adopted which seemed to be in best agreement with the observations. One observation on the

[1] *Astrophysical Journal*, **27**, 125, 1908.

rapidly descending branch of the curve gave an abnormal residual, which was probably the cause of the large number of least-squares corrections required.

With these elements which are given below it was decided to make a least-squares solution, using the differential equations of Lehmann-Filhés. Fourteen observation equations, connecting the elements γ, K, e, ω, T, K', and T' with the residuals for each group, were formed and a corrected set of elements was obtained which greatly lessened the sum of the squares of the residuals. As the corrections were large a second solution was necessary. This second set of values again lessened Σpvv, but two more solutions, omitting corrections for γ and K', which were small in the second, were necessary before a satisfactory agreement between the residuals from ephemeris and equation was reached.

The following table gives the successive approximations to the values of the elements. It will be seen that Σpvv has been reduced from 3239 to 175, the greater precision arrived at justifying the extra labor involved in the least-squares solutions.

SUCCESSIVE APPROXIMATIONS TO ELEMENTS

Elements	Preliminary	1st Solution	2d Solution	3d Solution	4th Solution
U.....	27.160 days				27.160 days
γ.....	+26 km	+26.25 km	+26.12 km		+26.12 km
K.....	110 km	95.33 km	90.32 km	93.81 km	93.04 km
e.....	.85 km	.794	.748	.775	.765
ω.....	90°	95°.92	84°.13	89°.13	87°.02
T.....	2417961.517	544	463	481	465
$a \sin i$.....					22,380,000 km
K'.....	6 km	10.56 km	10.15 km		10.15 km
T'.....	2417973.070	...972.549	...974.373	...973.156	...973.791
Σpvv.....	3329	505	318	186	175

The curve Fig. 1 is drawn from the final elements, though the original elements gave a curve which to the eye appeared to suit almost as well. The circles represent our own observations, grouped; the triangles, individual observations at Yerkes—one of them unpublished as yet, being communicated through the kindness of Professor Frost.

Without going into detail to give the measures of the various plates

the accompanying table will show the observations as grouped, the phases being reckoned from the periastron finally adopted.

NORMAL PLACES

No.	Mean Phase	Mean Vel.	Wt.	O −C.
		km		km
1	0.052	+ 27.27	1.5	+2.78
2	1.882	− 50.05	1.5	−3.65
3	4.489	− 9.25	2.0	+5.39
4	6.705	+ 2.44	2.5	+1.52
5	8.635	+ 8.60	4.0	−0.98
6	10.809	+ 16.67	3.0	+0.68
7	14.120	+ 21.70	1.0	−1.59
8	16.979	+ 28.90	1.0	−2.72
9	19.112	+ 45.64	1.5	+4.25
10	22.504	+ 66.91	2.0	−0.37
11	24.149	+ 87.10	0.5	−0.40
12	25.584	+110.40	1.0	−2.02
13	26.421	+125.90	2.5	+2.32
14	27.059	+ 58.15	1.5	−3.62

The probable error of a normal place of weight unity is ±2.97 km per sec. When the residuals for each plate were determined separately

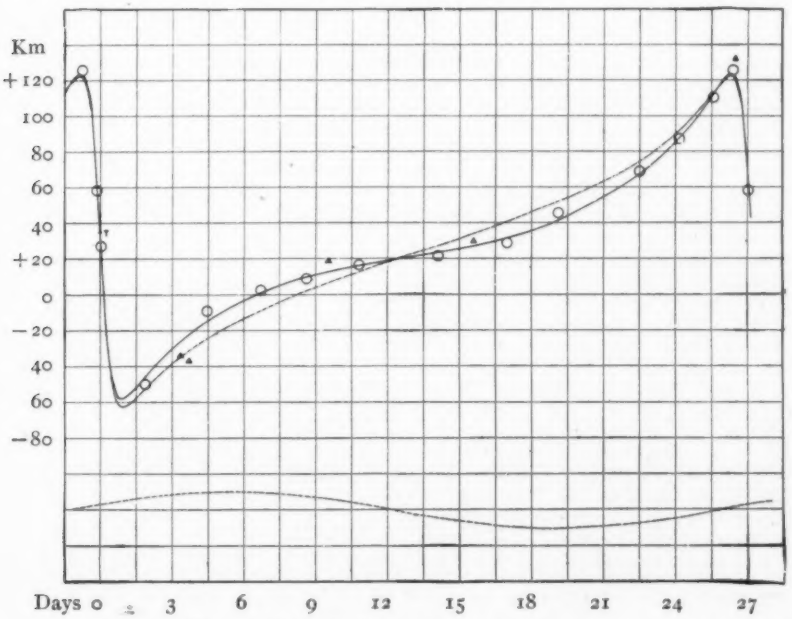


FIG. 1.—Velocity-Curve of *B. D.* −1°1004

by scaling from the final curve the probable error of an average plate was ±5.2 km per sec. With two abnormal residuals around periastron omitted—in one, No. 2026, the exposure was prolonged and temperature in prisms changed—this value reduces to ±4.6 km

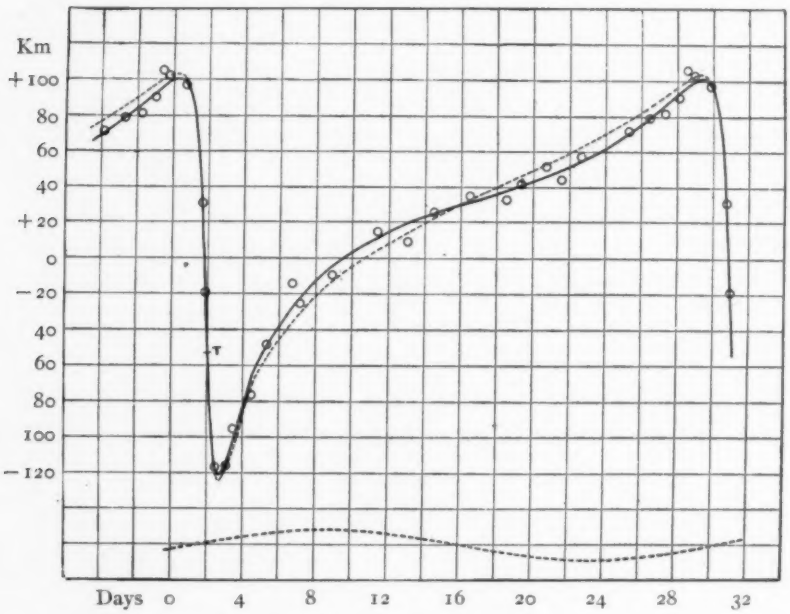


FIG. 2.—Velocity-Curve of ι *Orionis*

per sec. The diameter of the circles in the curve represents the probable error ±5.2.

A graph of the orbit is shown in Fig. 3.

More plates of this star will be made during the coming season to determine definitely the maximum velocity to earth. It is expected that it will not differ materially from that which has been assumed in this determination.

As mentioned above, the similarity of the velocity-curves and of the elements of the two stars and the undoubted presence of a secondary effect in the latter, with its probable presence in the former, were deemed sufficient reason for a redetermination, with the addition of terms for the secondary, of the orbit of ι *Orionis*. Accordingly such a solution by the method of least-squares was performed by Mr.

Plaskett. For the preliminary elements of the primary those determined graphically, as better suited to the application of the secondary, were taken; while for the latter, simple circular motion of half amplitude 7.0 km and of the same period was superposed on the primary, the crossing points being taken at periastron and apastron.

The first solution showed greater differences than seemed desirable between the residuals from ephemeris and equation and a second solution was made. The differences between residuals then became satisfactory, and as the table of elements shows, the second corrections are very small. The velocity-curve corresponding to the final elements is shown in Fig. 2 in the heavy curve, the dotted curves representing the primary and secondary components. For comparison the elements without secondary are tabulated beside those with secondary.

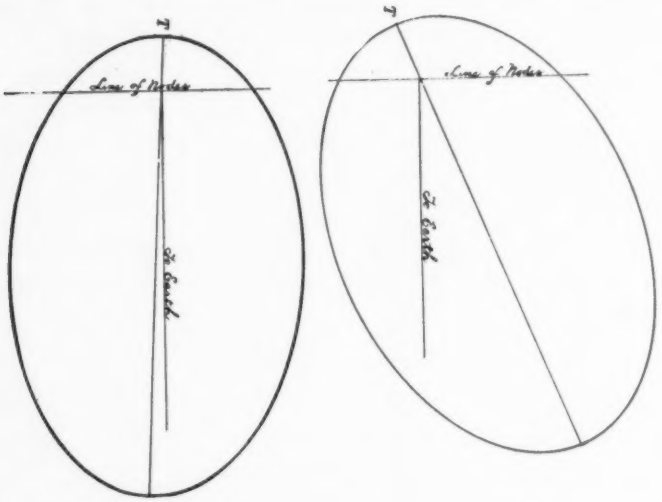
FINAL ELEMENTS ι *Orionis*

Element	Preliminary	Solutions with Secondary		Simple Solution
		First	Second	
K	112.0 km	113.544	113.681	109.90
e	0.75	0.7406	0.7415	0.7543
ω	110.0	112°.315	112°.374	113°.28
T	*J. D.* 7,587.94	7.9896	7.9911	7.993
K'	7.0 km	8.427	8.381	
T'	7.94	7.2675	7.3545	
γ	+20.7 km	21.511	21.532	21.34
$a \sin i$	29,680,000 km		30,560,000	28,907,000

A comparison of Fig. 2 with the original velocity-curves shows an improvement in the agreement of normal places and curves by the introduction of the secondary, and this is further demonstrated by the decrease in the probable errors, etc., as shown in the following table:

	Without Secondary		With Secondary	
	Preliminary	Corrected	Preliminary	Corrected
Σpvv	2994	2181	1683	1316
Prob. error normal place of unit weight	±8.0	±6.9	±6.3	±5.5
Prob. error average normal place	±3.8	±3.3	±2.9	±2.5
Prob. error single plate		±7.7		±6.8

There appears to be no doubt of the observations being better suited by the orbit with secondary and this, taken in conjunction with the similarity to the star *B. D.* -1° 1004, where the presence of a secondary is undoubted, seems definitely to settle the question.



B. D. $-1^{\circ}1004$ ι *Orionis*

FIG. 3.—Graph of Orbit

Comparison.—The similarity between these two binary stars in position, in spectral type, and in the elements of their orbits seems almost too marked to be accidental, although we know no apparent common cause capable of producing such similarity. The orbits of both stars are singular in their high eccentricity, in their high range of velocity, and especially in having a secondary disturbance of the same period as the primary. One spectroscopic binary only of those so far determined, β *Arietis*, has an eccentricity greater than 0.75, and although there are several binaries with secondaries of periods sup-multiple of the primary, none up to the present, so far as known, has secondary periods equal to the primary.

The points of similarity may with advantage be briefly referred to:

1. Position in the sky:

ι *Orionis*, . . . R. A. 5^{h} 30^{m} Dec. -5° 59′
B. D. $-1^{\circ}1004$, R. A. 5^{h} 36^{m} Dec. -1° 11′

Both in the constellation of *Orion* and within 5° of one another.

2. Spectral type:

   Both are *Orion* or helium stars having diffuse lines of hydrogen and helium with occasional metallic lines and traces of the second hydrogen series. The measures depend, however, almost entirely upon the hydrogen and helium lines.

3. Periods:

   ι *Orionis*, . . . 29.136 days
   B. D. $-1°.1004$, 27.160 days

   Both are practically one month.

4. Eccentricities:

   ι *Orionis*, . . . 0.74
   B. D. $-1°.1004$, 0.76

   Both are exceptionally high for spectroscopic binaries.

5. Amplitude or range of velocity:

   ι *Orionis*, . . . 227 km
   B. D. $-1°.1004$, 186 km

   Both are considerably higher than the average, probably indicating that the planes of the orbits are not far from the line of sight.

6. Longitude of the apses:

   ι *Orionis*, . . . $112°.4$
   B. D. $-1°.1004$, $87°.0$

   In both systems the major axis is nearly parallel to the line of sight.

7. Velocities of the systems:

   ι *Orionis*, . . . +21.5 km per second
   B. D. $-1°.1004$, +26.1 km per second

   Both are of the same order and practically the same.

The most striking similarity is however undoubtedly in the secondary disturbances, which are almost identical in period amplitude and phase.

8. Periods of the secondaries in both the same as the period of the primary, something so far unknown in spectroscopic binaries. Observations in both apparently well satisfied by assumption of circular motion of secondary superposed on elliptical motion of primary.

9. Amplitudes or range of velocities of secondaries:

   ι *Orionis*, . . . 16.8 km
   B. D. $-1°.1004$, 20.2 km

   Practically the same, one-thirteenth and one-ninth, respectively, of the amplitudes of the primaries.

10. Times of secondary crossing primary:

ι Orionis, . . . −0.6 days before primary periastron
B. D. −1°.1004, −1.2 days before primary periastron

For comparison it may be said approximately that the time of crossing is coincident with the nearest approach of the bright pair.

11. On the assumption of the secondary being due to a revolving satellite the projection of the semidiameter of secondary, $a' \sin i$, is

ι Orionis, . . . 3,358,000 km
B. D. −1°.1004, 3,791,000 km

It is comparatively easy to point out the similarities in the two binaries, but to determine if this is due to a common cause and then to find this cause is quite another question. So far as the secondary effects are concerned, however, it may be safely inferred from their similarity that they are due to the same physical cause. Owing to the secondary being of the same period as the primary, with the high eccentricity of the latter, the line displacements observed are not likely due to the presence of a third body for, so far as known, such a system is dynamically impossible. On the other hand, the equality of primary and secondary periods would be some justification for connecting the secondary effect with the orbital revolution of the system, but whether due to a resisting medium, to tidal action, or to other causes, cannot at present be determined.

It is with much pleasure that we acknowledge the assistance of Director Dr. W. F. King, in some of the mathematical questions involved and his interest and encouragement in the work.

DOMINION OBSERVATORY
OTTAWA, CANADA
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THE EFFECT OF A MAGNETIC FIELD UPON THE ABSORPTION SPECTRA OF CERTAIN RARE EARTHS

By WILLIAM FREDERICK SCHULZ

INTRODUCTION

Although the great majority of solid substances when heated to incandescence give a continuous emission spectrum, it was discovered by Bunsen[1] in 1864 that didymium emits a bright band spectrum under these conditions. The same phenomenon was observed with erbium by Bahr[2] in the following year, and since then a few more of the rare earths have been shown to possess the same peculiarity. The absorption spectra of these rare earths are of special interest, it being by means of these spectra that some of them were discovered. So far neodymium, praseodymium, samarium, erbium, holmium, dysprosium, thulium, and europium are the only ones found to give a line absorption spectrum. Because of their interest and peculiarities, the comparatively great number of bands, and the relatively small width of some of the latter, these substances have been the subject of spectroscopic investigation by a large number of observers.

One of the methods extensively used is to form the absorption spectrum by means of a beam of intense light after reflection from one of the salts of the element to be studied. This method was first used by Haidinger[3] in 1852.

As some of the results of these experiments have a direct bearing on the subject of this research they will be briefly reviewed here.

It was noted as early as 1831 by Brewster that the transparency and color of certain solids were altered when they were heated, but Conway in 1891 was the first to make spectroscopic measurements of this change and showed that the bands of cobalt glass were shifted toward the red end of the spectrum as the temperature increased.

Recently J. A. Anderson[4] investigated the effect of increase of temperature upon the absorption bands of erbium and neodymium

[1] *Liebig's Annalen*, **131**, 255, 1864.
[2] *Ibid.*, **135**, 376, 1865.
[3] *Wien. Ber.*, **8**, 97, 1852.
[4] *Astrophysical Journal*, **26**, 73, 1907.

compounds, and J. Becquerel,[1] using liquid air as a cooling medium, experimented with crystals containing these and other rare earths, and also with solutions of their salts in various alcohols, the solutions of course being solid at the temperature used.

The effect upon the absorption bands was threefold: As the temperature was lowered, they were shifted from their original positions; they became narrower and sharper, and at the same time more intense. Some of the bands were shifted toward the red end of the spectrum, while others moved in the opposite direction.

J. Becquerel and J. K. Onnes[2] later repeated the experiments, using liquid hydrogen for the cooling bath. It was found that at this lower temperature some of the lines again became broader, some of them actually disappearing, whereas new ones appeared which were not observed at ordinary temperatures.

Becquerel[3] also studied the effect of a magnetic field upon the absorption bands of the transmission spectrum of these crystals, both at ordinary and at very low temperatures. It was found that some of the bands were not at all affected, others simply becoming broader and changing in intensity in the magnetic field, whereas in yet others the effect was similar to the Zeeman effect in vapors. The magnitude of these effects was found to be proportional to the strength of the field and independent of the temperature. Uniaxial and biaxial crystals were used and naturally the effect depended upon the relative positions of the crystal with respect to the beam of light and the direction of the magnetic field. The result of this investigation may be briefly described as follows:

Case I.—The beam of light perpendicular to the direction of the magnetic field.

The spectrum corresponding to rays polarized perpendicular to the field differed from that corresponding to rays polarized parallel to the field. Certain rays were split up into triplets, the outer components of these triplets, for some bands, being found in one of the above spectra, for other bands in the other spectrum.

As the optical axis of the crystal was rotated in a plane parallel to the beam of light and to the direction of the lines of force, it was

[1] *Comptes Rendus*, **144**, 420, 682, 1032, 1336, 1907. [2] *Ibid.*, **146**, 625, 1908.

[3] *Ibid.*, **142**, 775, 874; **143**, 890, 962, 1906; **144**, 132, 1907.

found that some of these components in the ordinary spectrum themselves split up into a doublet, some of the new components increasing in intensity as the rotation proceeds, others becoming feebler and finally disappearing. The displacement of some of the bands is greater than would be expected from a knowledge of the Zeeman effect. At ordinary temperatures the field-strength used was in the neighborhood of 30,000 Gauss, but at the lower temperatures the separation could be noted with field-strengths of about half this amount.

Case II.—The beam of light parallel to the field of force.

If we were observing the Zeeman effect upon the emission lines of a vapor under this condition, and passed the light through a quarter-wave plate and a rhomb of spar properly oriented, we would see in the spectrograph two contiguous spectra, plane polarized at right angles to each other. These two spectra correspond to light circularly polarized in opposite directions. The circularly polarized components of each doublet produced by the magnetic field are equally displaced from the position of the original line, but in opposite directions.

For this arrangement of the apparatus Becquerel obtained components of his bands which were shifted in opposite directions in the two spectra. We may think of these components as corresponding to circular vibrations in opposite directions, the direction of vibration being in each case opposite to that of the light which actually gets through the apparatus when the plate and prism are not inserted, and Becquerel so speaks of them.

He found also that in the same spectrum the components of different bands were shifted in opposite directions.

Since in the Zeeman effect the rays corresponding to negative electrons with paths in the same sense as that of the magnetizing current are always shifted toward the shorter wave-lengths, the above fact would indicate that there are positive electrons present in the crystals, or else that there is a change of direction of magnetic field within certain atoms. Becquerel accepts the first of these hypotheses.

He calculated the value of e/m for these positive electrons from the separation of the components of different bands and found it to be from three to nine times the value of this ratio for kathode particles.

Rotary magnetic polarization was observed[1] by passing a beam of plane-polarized white light through a plate of crystal cut normal to the axis, and then through a rhomb of spar placed in front of the slit of the spectrograph and so oriented that two contiguous strips, polarized in different planes but having the same intensity, could be seen at the same time. When a magnetic field was set up parallel to the incident beam the bands of the ordinary absorption spectrum were found to change in intensity. The bands corresponding to negative electrons, in one of the strips, became more intense and narrow, whereas those corresponding to positive electrons became less intense and broader. In the other strip the effect was just reversed, and the whole effect was reversed when the direction of the field was changed by reversing the magnetizing current. Becquerel states that "on each side of the absorption bands which form a doublet, the rotatory power is positive (in the sense of the magnetizing current) if the band corresponds to negative electrons, and negative if the band corresponds to positive electrons. Within each band or between the components of certain of them, the sense of the rotation is opposite to that outside of the band."

Becquerel mentions[2] that these crystals contain paramagnetic substances (erbium, didymium, etc.). Now according to Curie's law paramagnetic susceptibility is proportional to the absolute temperature, whereas diamagnetism is independent of the temperature. Having found that the change of period of vibration of electrons in these crystals is independent of the temperature, he seeks for a connection between these changes and diamagnetism.

From his theoretical investigation Becquerel concludes that the period of the motion proper to the electrons is not influenced by the temperature in the solid body, but that the resistance experienced by the electrons in vibration increases and diminishes with the temperature. An analytical investigation of these effects led W. M. Page[3] to the following conclusions:

1. If the electron is easily displaced from its equilibrium position, a large separation of the components of the doublet will result from the action of a magnetic field.

[1] *Comptes Rendus*, **142**, 1144, 1906; **144**, 682, 1907. [2] *Le Radium*, **5**, 5, 1908.

[3] *Cambridge Phil. Soc. Trans.*, **20**, No. 13, 291, 1907.

2. If the friction is small the bands will be very dark and narrow, while if the friction is large, the bands will be wide and will shade off very gradually from the point of maximum intensity. Thus when the crystal is acted on by a magnetic field, the components of the resulting doublet will run into one another and the separation will not be observed, though the bands on the whole will increase in breadth.

3. The fact that some of the bands observed broaden for some directions of the vibrations and separate for others, is held to indicate that the friction is different in different directions.

4. The vibrations are preferably ascribed to negative electrons in all cases, it being held that in the neighborhood of systems that give "inverse" displacements, the magnetic field changes sign, i. e., that these inverse effects are diamagnetic in character.

OBJECT OF THIS INVESTIGATION

The fact was brought out by Anderson that when an absorption spectrum was obtained by reflection from the fused surface of the oxide of erbium or of neodymium, the spectrum was identical with that obtained from the unfused oxide except that the absorption bands were very much more intense in the former. This indicated that the absorption bands are really due to the fact that the light is transmitted through a thin layer of the substance, the increased intensity being due to the longer path through the more transparent fused oxide.

It was therefore determined to investigate whether the absorption bands obtained in this manner are affected by a magnetic field in the same way as those obtained by transmission through crystals.

PREPARATION OF MATERIALS

The salts of erbium and of neodymium are known to show a large number of absorption bands which are comparatively narrow and sharp. It was therefore determined to use the oxides of these elements as the reflecting surfaces.

The chlorides of these elements[1] were first precipitated by the addition of a concentrated solution of oxalic acid. After being washed with hot water to remove any remaining oxalic acid, the precipitates were dried and then heated in porcelain vessels to a red heat, being

[1] The chlorides used were some of those prepared by Dr. Anderson during his investigation of these elements.

thus converted into oxides. The erbium salts were found to be free from neodymium, praseodymium, and holmium.

To use these oxides as reflecting surfaces they were formed into small plates about $\frac{1}{2} \times 2 \times 3$ mm in dimension. The powdered oxide was moistened with chloride solution and then packed into a small glass mold, a fine platinum wire being forced into the mixture before it hardened. By means of this wire the plates were readily handled after they were dried. The plates were toughened by alternately dipping them into the chloride solution and gradually heating them to redness.

As was shown by Anderson the absorption bands obtained from these oxides are much darker and more distinct if the reflecting surfaces are fused. The plates of erbium were therefore heated for several hours in the oxyhydrogen flame after they had been toughened. It was found that the neodymium oxide when treated in this manner became so dark that it was rendered unfit for use. It was therefore heated for several hours in the Bunsen flame and then for only a short time in the oxyhydrogen flame.

ARRANGEMENT OF APPARATUS

The spectrum was observed by means of a fixed-arm spectrograph having an objective with a focal length of 160 cm. A plane Rowland grating on speculum metal having a space of $3\frac{3}{8}$ inches ruled with 20,000 lines to the inch was used.

The reflecting plate was placed between the poles of a large Ruhmkorff electromagnet,[1] and was strongly illuminated by focusing the light from the positive pole of a carbon arc lamp upon it, the reflected beam being focused upon the slit of the spectrograph.

In order to observe side by side the spectra polarized in planes perpendicular to each other, the beam of light was passed through a properly oriented double-image prism before falling on the slit of the spectrograph.

METHOD OF OBSERVATION

The reflected beam of light was rather faint, and it was found advantageous to focus the light upon the slit by means of a cylindrical lens. The effect of the magnetic field upon the absorption bands

[1] For some of the observations, use was made of a small du Bois magnet belonging to the U. S. Bureau of Standards.

could, however, be plainly seen with the naked eye except in the region of short wave-lengths.

In order to measure the effects more accurately and to compare the spectra obtained with and without the magnetic field, they were photographed.

The two spectra were observed side by side by alternately masking the two halves of the slit. But the camera was so arranged that when this was not possible, a freely moving screen could be moved up and down in front of the plate, this screen having a slit large enough to permit the full spectrum (obtainable with this apparatus) to be photographed.

This spectrum covered a range of 500 Ångström units, and it was proposed to study in particular three groups of bands of erbium oxide, which were more intense than the others, and which were found in the regions between λ 4450 and λ 4760, λ 5150 and λ 5650, λ 6300 and λ 6800, respectively. (See Figs. 1 and 2.)

In the case of neodymium oxide the band at λ 4375.2 and those lying between λ 5300 and λ 5500, and between λ 5800 and λ 6200 were observed.

The time of exposure was limited because of the heating of the electromagnet, owing to the heavy currents which were required to produce the strong fields that were used. It was therefore necessary to use the quickest photographic plate that was sensitive in the particular region to be investigated. A large number of plates of various kinds were experimented with, and finally the following were chosen as giving the best results in the limited time at our disposal: for the blue region of the spectrum, Seed's Gilt Edge No. 27; for the green region, Cramer's Isochromatic; and for the red region, the Wratten & Wainwright Panchromatic plates.

In order to gain the advantage of narrow and intense bands at low temperatures, an attempt was made to cool the reflecting plate by directing a fine stream of ethyl chloride upon its surface. The effect produced was hardly noticeable and this method was abandoned. The air gap between the poles of the electromagnet was generally less than one millimeter in order to obtain the strongest possible field, so that it was impracticable to immerse the plate in liquid air within this gap.

A water-screen was for a time placed in the path of the incident beam to prevent heating of the reflecting plate, but this was found to be unnecessary, the heating effect being negligible in comparison with the magnetic effect.

Several photographs were taken of the second-order spectrum but nothing new was brought out by these, and as the time of exposure was limited, the majority of the photographs were taken of the first-order spectrum.

The effect of the magnetic field was observed: (1) when set up perpendicular to the beam of reflected light, and (2) when set up parallel to this beam. In the latter case a quarter-wave plate and double-image prism were arranged in the manner already described, which would in the case of the ordinary Zeeman effect give two spectra corresponding to circularly polarized components of opposite sense. We will speak of the two spectra obtained in the case of absorption bands, as corresponding to opposite circular vibrations, using this phrase in the same sense that Becquerel used it.

The core of the magnet was bored with a $\frac{3}{4}$-inch hole, the pole piece with a $\frac{3}{16}$-inch hole. The axis of this opening was in line with the middle of the slit and with the center of the grating. In the first experiments a small right-angled prism was placed in front of this opening and an arc lamp to one side of the magnet, so that the beam of light reflected into the opening by the prism and falling upon the erbium or neodymium oxide plate retraced its path parallel to the lines of force.

The reflected beam was rather feeble and required so long a time for exposures that a strong field could not be used. The prism was therefore discarded and the following arrangement was substituted.

The reflecting plate was placed between the pole-pieces at an angle of about forty-five degrees with the direction of the field. The source of light was placed to one side of the magnet so that the light falling upon this inclined plate was reflected through the opening parallel to the lines of force.

There was no noticeable difference between the photographs obtained with these two arrangements.

RESULTS OF OBSERVATIONS

The field strength was varied from 18,000 to about 27,000 Gauss and the magnetic effect was found to be proportional to the strength of the field.

Erbium oxide. Case I.—The direction of the magnetic field perpendicular to the beam of light.

Under these conditions it was found that some of the bands were not appreciably affected. Others were considerably broadened both in the ordinary and in the extraordinary spectrum. It was observed, however, that the broadening was greater in one case than in the other, and upon examination with a Nicol prism, the broader of the two was found to be due to vibrations perpendicular to the lines of force of the field, the other being due to vibrations parallel to the field. Reversing the magnetic field did not alter the appearance of these bands. The narrower band evidently corresponds to the middle component of the ordinary Zeeman triplet, the broader band to the outer components. It was noticed, however, that in all the photographs the spectrum due to vibrations parallel to the field was considerably denser than the other, probably owing to the polarization introduced by the grating. The difference in width may therefore have been in part due to this different density.

Not even with the strongest field used could a positive separation of the two outer components be detected, although in some cases the width of the bands is increased in the magnetic field about one and a half times.

Still other bands were found to be shifted from their original positions when the magnetic field was set up. Some of these were moved toward the red end of the spectrum; others toward the violet end.

In other cases the bands were unsymmetrically broadened, the broadening being in opposite directions for different bands.

There is also a marked change in the intensity of the bands when in a magnetic field. As they become broader they decrease in intensity, some of them actually disappearing.

The difference in breadth of the bands in the spectra polarized at right angles to each other is clearly seen in the isolated band at λ 5197.0. This is shown in Fig. 3, which is the group marked "B"

in Fig. 1, but on a larger scale. Taking the average width of this band from three different plates it was found to be about 3.7 Å. U. when the field was not excited. In the magnetic field, the width changed to about 4.7 Å. U. and 5.1 Å. U. respectively for the two spectra, with a field strength of approximately 25,000 units.

In the same group the band at λ 5250.0 does not seem to be affected by the field.

The band at λ 5242.2 is much broadened, the width in the magnetic field being about one and a half times as great.

The bands at λ 5212, λ 5232, and λ 5268.8 in this group show marked decrease in intensity. The one at λ 5232 is no longer visible in the magnetic field. The one at λ 5212 may still be seen in the spectrum polarized parallel to the field but not in the other. The band at λ 5268.8 can be seen in the spectrum polarized perpendicular to the field, but not in the one parallel to the field.

The other bands in this group seem to increase in width in the manner first described.

Fig. 6 shows on a larger scale the group of bands marked "C" in Fig. 2. In this group the band at λ 6630 shows no appreciable change in the magnetic field. The one at λ 6617 is much broadened, the broadening being unsymmetrical and toward the red end of the spectrum. On the other hand, the band at λ 6524 also broadens unsymmetrically but toward the violet end of the spectrum. The other bands of this region are all more or less broadened.

In Figs. 4 and 5 the group marked "A" in Fig. 1 is shown on a larger scale. The band at λ 4499 shows no change in the magnetic field. The band at λ 4510.5 changes very little in breadth but is shifted toward the violet end of the spectrum by approximately 0.6 Å. U. for a field strength of 25,000 units. The broad band at about λ 4486 appeared to become narrower and more intense in the magnetic field. The narrowing seemed to be all on one side, but it was thought probable that the band was shifted, the shift of one edge being hidden by an emission band from the source of light at this point. This is shown in Fig. 4. To avoid this band, the spectrum was photographed by means of a Nernst lamp. The time of exposure was, however, so much increased that a strong field could not be used. A satisfactory photograph free from emission lines was finally obtained by making

PLATE XII

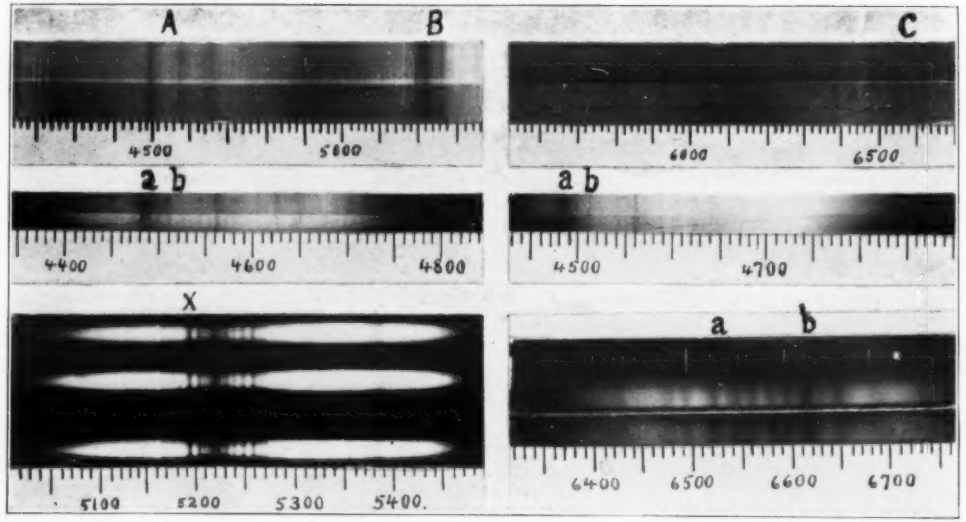

FIG. 1 (2, 1)

FIG. 2 (1, 2)

FIG. 4 (2, 1)

FIG. 5 (1, 2)

FIG. 3 (2b, 2a, 1)

Iron Arc

FIG. 6 (1, 2)

ERBIUM OXIDE

Spectra marked 1 were photographed without the magnetic field.
Spectra marked 2 were photographed with the field.

Group A. Bands examined, between λ 4450 and λ 4700.
Group B. Bands examined, between λ 5150 and λ 5650.
Group C. Bands examined, between λ 6300 and λ 6800.

FIG. 4.—Group A of Fig. 1
Photograph with Carbon Arc.

FIG. 5.—Group A of Fig. 1
Photograph with Acetylene Flame.

a. Band at λ 4482.2 shifted toward red.
b. Band at λ 4510.5 shifted toward violet.

FIG. 3.—Group B of Fig. 1

2*a*. Vibrations parallel to field.
2*b*. Vibrations perpendicular to field.
x. Band at λ 5197.

FIG. 6.—Group C of Fig. 2

a. Band at λ 6524 broadens unsymmetrically to violet.
b. Band at λ 6617 broadens unsymmetrically to red.

use of the scheme devised by C. F. Lorenz,[1] the intensity of an acetylene flame being increased by passing an electric discharge through it. This photograph is shown in Fig. 5. It now appeared as though there was an unsymmetrical shift of the band, but upon close examination the band proved to have two distinct maxima. Under the influence of the magnetic field, the one at λ 4482.2 became broader and was shifted toward the red end of the spectrum by approximately 0.8 Å. U. for a field-strength of about 25,000 units. The other component of this band became broader in the magnetic field but retained its position.

The band at λ 4562.6 becomes somewhat broader and shifts slightly toward the violet side. The remaining bands of this group are all more or less broadened in the magnetic field.

Erbium oxide. Case II.—The lines of force of the magnetic field parallel to the beam of light.

The spectra produced under these conditions showed the same changes as those obtained when the field was perpendicular to the beam of light. The same bands as before became broader and the same bands were shifted from their original position.

No positive evidence of displacements in opposite directions of the two components of a band corresponding to opposite circular vibrations could be detected. To test the bands for circular polarization, the quarter-wave plate and a Nicol prism were placed before the slit and so oriented that if the edges of the band were circularly polarized one of them would be cut off. If, now, the direction of the field were reversed, the direction of polarization should change also, and the other edge of the band should appear, the first one being now cut off. No change of position of the bands resulted in this experiment.

It was thought that if plane-polarized light were used in the incident beam, there might still be some trace of polarization left in the diffusely reflected light, so that it might be possible to observe the effect noticed by Becquerel and ascribed to magnetic rotatory polarization, that is, the broadening of the bands due to negative electrons and the corresponding narrowing of the bands due to positive electrons, in the same spectrum. This was accordingly tried, but the photographs showed the same effect in all cases as when ordinary light was used.

[1] *Physikalische Zeitschrift*, **8**, 20, 1907.

Neodymium oxide.—The bands for this substance were in general broader and not so sharply defined as in the case of erbium oxide.

ERBIUM OXIDE

λ	Nature of Band	Effect
4482.2	Wide and intense	Broadens and shifts to red
4491.3	Wide and intense	Broadens
4510.5	Wide and intense	Broadens slightly; shifts to violet
4541.9	Narrow and intense	Broadens
4554.1	Narrow and faint	Broadens
4562.6	Broad and intense	Broadens and shifts to violet
4571.8	Broad; hazy	Broadens
4579.1	Broad; hazy	Broadens
4606.5	Narrow and faint	Broadens
4625.9	Broad and faint	Broadens
5197.0	Broad; sharp	Broadens
5205.5	Broad; sharp	Broadens
5212	Narrow; faint	Becomes very faint or disappears
5216.5	Narrow; faint	Becomes very faint or disappears
5232	Narrow; faint	Becomes very faint or disappears
5242.2	Narrow and intense	Broadens very much
5250.0	Broad and faint	Not affected
5261.0	Broad and faint	Broadened
5268.8	Broad and faint	Becomes very faint and disappears
5387.7	Broad and faint	Broadens
6430.0	Broad and faint	Broadens
6476	Broad and faint	Broadens
6496	Broad and very hazy	Broadens
6524	Broad and very hazy	Broadens unsymmetrically to violet
6538	Broad and very hazy	Broadens
6546	Broad and distinct	Broadens
6562	Broad and distinct	Broadens
6581	Broad and hazy	Broadens
6598	Broad and hazy	Broadens
6617	Broad and distinct	Broadens unsymmetrically to red
6630	Broad and hazy	Not affected
6652	Broad and hazy	Broadens

NEODYMIUM OXIDE

λ	Nature of Band	Effect
4375.2	Narrow; faint	Broadens
5355	Broad; dark	Broadens
5379	Broad; dark	Broadens
5403	Narrow; dark	Broadens
5853	Broad; edges hazy	Broadens
5902	Very broad; edges hazy	Broadens
6103	Very broad; edges hazy	Broadens
6148	Very broad; edges hazy	Broadens
6197	Broad; edges hazy	Broadens

The same experiments were carried out, but no new effects were observed. The general result of placing the substance in the magnetic field was to broaden the bands. None of these was observed to shift. It was noticed in the course of the investigation that the oxides of erbium and of neodymium are quite strongly magnetic. If not securely fastened, the reflecting plates were drawn into the strongest parts of the field, thus shifting the light from the slit or getting out of focus. A rod of the oxide, when suspended in the field so that it could rotate, placed itself parallel to the lines of force.

A tabie of the bands observed, their wave-lengths and appearance, and the effect of the magnetic field upon them is appended.

DISCUSSION OF RESULTS

It is known that the position of the absorption bands of an element is different for different compounds of the same element, and that it changes with temperature, concentration of solution, etc. The bands found for the erbium and neodymium oxides were quite different from those studied in crystals by Becquerel, and it was difficult to compare effects in the two cases. Becquerel gives the position of bands which gave him a large value of e/m for positive electrons as λ 5206.5, λ 5211.3, λ 5236.6, λ 5245.8, λ 6474.0, λ 6505.6, and λ 6542.5 for the erbium compounds. The bands obtained with the oxides in these neighborhoods were carefully examined, but no difference could be found between these and the others. He gives the band at λ 6571.6 as displaced toward the red end of the spectrum. In this neighborhood the band at λ 6617 for the oxide was also displaced toward the red.

As was pointed out by Page (*loc. cit.*) when the resistance to vibrations of electrons is great, the bands will be comparatively wide and the effect of the magnetic field will be to broaden them, the components overlapping each other. But even the narrow bands showed no complete separation of their components in this investigation.

The fact that no positive evidence of circular polarization could be detected may be explained by the fact that the light in order to show absorption bands must penetrate a thin layer of the reflecting substance. In its passage through this layer the light will change its direction from particle to particle, being at times more or less paral-

lel to the direction of the negative field, at times perpendicular to this field. Apparently the broadening of the bands due to the absorbing electrons when the path is perpendicular to the lines of force is sufficiently great to mask the effect when the light is parallel to the field, so that we see the broadening of the bands in all cases.

The unsymmetrical broadening of some of the bands in opposite directions may be really due to the fact that certain bands are much more affected by the magnetic field than others. If, for instance, a band is really double, the components lying so close together that they cannot be seen separately, and if one of these is much more affected than the other in a magnetic field, the broadening of this component will make the band as a whole appear to be broader and shifted in the direction of this component. The direction in which this apparent shift takes place will then depend upon which of the two component bands is the more broadened by the magnetic field.

SUMMARY

As a result of this investigation upon erbium and neodymium oxide, it may be stated that the absorption spectra obtained by reflection from these substances show the following effects in the magnetic field, for the temperature and field-strengths used:

1. Practically no difference was observed between the two spectra obtained, first with the light parallel to the field and secondly with the light and field perpendicular to each other.

2. Certain bands are not affected by the magnetic field.

3. Other bands appear to be shifted from their original positions, some toward the red, others toward the violet end of the spectrum.

4. Certain bands become broader in the magnetic field, the increased width appearing to be greater in the case of vibrations perpendicular to the field than for vibrations parallel to the field. This difference in width may be partly accounted for by the fact that one spectrum is denser than the other, which is probably due to polarization by the grating.

5. A number of bands were found to be unsymmetrically broadened, the broadening being in some cases greatest toward the red end of the spectrum, in other cases toward the violet end.

6. The intensity of the bands is altered in the magnetic field; some of them actually disappearing.

7. The oxides of both erbium and neodymium are paramagnetic.

In conclusion, I wish to thank Professor J. S. Ames, under whom this work was carried out, for his unfailing interest and advice during its progress. My thanks are also due to Dr. S. W. Stratton for the loan of the du Bois magnet.

Minor Contributions and Notes

CORRECTION TO PROFESSOR KAPTEYN'S ARTICLE IN THE NOVEMBER NUMBER

In the footnote on page 285 of my paper "On the Absorption of Light in Space" in the November number of this *Journal* occur the following words:

> An objection may be raised against both formulae (2) and (3). In the absence of data for the individual values of M and Δ in equation (4) we may expect good results if we introduce values which are correct on the average. Now, however, if π be the average parallax of a certain class of stars, then Δ, computed by (3), will *not* generally be the average distance, nor will M computed by (2) be the average absolute magnitude. Owing to the relative smallness of the deviations of the real parallaxes from those computed by our table (cf. *Groningen Publications*, No. 8, pp. 20–23), this objection cannot be considered as very serious, however.

The supposition made turns out to be sensibly in error. The passage referred to (*Groningen Publications*, No. 8, p. 21) contains all the data necessary to transform Table G (*l. c.*, p. 31), giving average parallaxes, into a table giving average distances. For, according to the data there given, we have: Probability that the parallax is contained between the limits π and $\pi+d\pi$

$$= \frac{h\mu}{\sqrt{3.1416}} \cdot \frac{1}{\pi} e^{-h^2\left(\log\frac{\pi}{\pi_0}\right)^2} d\pi$$

where

μ = modulus of the Naperian logarithms,

$h = \frac{0.47694}{\rho}$

By the aid of this probability, there is not the slightest difficulty in deriving both the average parallax $\bar{\pi}$ and the average distance $\bar{R}$ = average value of $\frac{0''.1}{\pi}$.

We thus find

$$\bar{R}=\frac{1}{10\pi}e^{\frac{1}{2h^2\mu^2}}.$$

Now we have (*l. c.*, p. 23)

$$\rho=0.19;\quad \text{consequently } h=2.510.$$

Therefore

$$(a)\quad \bar{R}=1.523\frac{1}{10\pi}$$

whereas we assumed

$$(b)\quad \bar{R}=\frac{1}{10\pi}.$$

The distances adopted for our individual stars have, therefore, to be multiplied by 1.523.

The averages for our different groups (included within determined limits of proper motion) have further to be increased for the same reason; which is, that the relation (*b*) which obtains between parallax and distance for an individual star is *not* valid for averages. Direct trial showed that within our groups the range of parallax is such that, in the mean, the factor 1.523 will have again to be increased by about $\frac{1}{8}$ of its amount.

Taking the two effects together, I find that our distances have to be multiplied by the factor 1.71.

The consequence is that the value brought out for the selective absorption must be divided by this number. Our final result (p. 316 of this volume) is therefore to be replaced by the following:

$$d=+0.0031\pm0.0006 \text{ Mag.}$$

J. C. KAPTEYN

GRONINGEN
November 1909

ERRORS IN WAVE-LENGTHS PUBLISHED BY COOPER IN THIS *JOURNAL*

I published in this *Journal* for June 1909 a paper entitled "Measurements of Wave-Lengths of the Spark Spectra of Chromium and Calcium: Also of the Arc Spectra of Cerium and Thorium: Together with a Study of the Possible Influence of Variations of Current, Capacity, etc., in the Spark Circuit," which gave the results of an investigation carried on in the physical laboratory of the Johns Hopkins University. Much to my regret, I have had called to my attention an error in my method of calculation, which affects some of my results. No value can be attached to the wave-lengths which I gave for cerium and thorium, or to the wave-lengths of calcium between the lines λ 2208.82 and λ 2994.960, or to the wave-lengths of chromium between the lines λ 2132.749 and λ 3875.257.

I wish to add that the wave-lengths which in my opinion are trustworthy were all calculated while I was still in residence at the Johns Hopkins University, using the well-known methods practiced in the physical laboratory of that institution. I was compelled by circumstances to leave there before completing my calculations, and the rest of my work I did elsewhere on my own responsibility. When Professor Ames gave his consent to the publication of my paper as a contribution from his laboratory, he had every reason to believe that my last calculations were made following his method, because I failed to call his attention to the fact that I had used another.

It is my intention to make a recalculation of the wave-lengths at as early a date as possible.

FRANK L. COOPER

ERRATA

Vol. **30**, November 1909, in M. Fabry's note "On the Size of Meteors":

Page 319, line 22, *for* 24.5 mm, *read* 5.4 mm.

Page 319, footnote 2, *for* luminosity *read* illumination.

INDEX TO VOLUME XXX

SUBJECTS

PAGE

ABSORPTION of Light in Space, Evidence from Photographic Color-Filters in Regard to. *J. A. Parkhurst* 33
of Light in Space. Second Paper. (See also Correction, p. 398.) *J. C. Kapteyn* 284
Spectra of Certain Rare Earths, Effect of Magnetic Field upon. *William Frederick Schulz* 383
AIR, Radiation Exponent of Dry. *W. J. Humphreys* 20
ALKALINE Earths, Spectra of Compounds of. *Albert Eagle* . . . 231
Andromeda Nebula, Note on Spectrum of. *J. Scheiner* 69
Spectrum of. *E. A. Fath* 167
ARC and Spark Spectrum of Mercury, Determination of Wave-Lengths (International System) for. *Harold Stiles* 48
and Spark Lines of Titanium, Manganese, and Vanadium, Redetermination of Wave-Lengths of. *Clinton Maury Kilby* . . 243
Spectrum of Vanadium in Region λ 5800 to λ 7364. *H. Shaw* . 127
ASTRONOMICAL and Astrophysical Society 168
BINARIES, Seven Spectroscopic. *S. A. Mitchell* 239
Two Curiously Similar Spectroscopic. *J. S. Plaskett* and *W. E. Harper*. 373
BINARY, Spectroscopic, *β Orionis*. *J. S. Plaskett* 26
CALCIUM, New Lines in Spectrum of. *James Barnes* 14
CAPACITY and Self-Induction, Effect of, on Wave-Lengths of Spark Lines. *Clinton Maury Kilby* 243
CHARTS, Celestial, by J. Palisa and M. Wolf. *J. Palisa* 70
COLOR-FILTERS, Evidence from, in Regard to Absorption of Light in Space. *J. A. Parkhurst* 33
COMET, Photographs of Halley's. *Oliver J. Lee* 237
1908 *c* (Morehouse), Spectrum of. *H. Rosenberg* 267
COMPARISON Prisms. *H. Konen* 318
DISPERSION of Light in Space, Apparent. *Paul R. Heyl* 40
EARTHS, Spectra of Compounds of Alkaline. *Albert Eagle* . . . 231
Effect of Magnetic Field upon Absorption Spectra of Certain Rare. *William Frederick Schulz* 383
ECLIPSE, Photography of "Flash" Spectrum without an. *George E. Hale* and *Walter S. Adams* 222
ERRATA:
Correction. *E. Hertzsprung* 320

PAGE

Correction to Professor Kapteyn's Article in the November Number. *J. C. Kapteyn* 398

Errors in Wave-Lengths Published in Cooper's Article in Vol. 29 of this *Journal*. *Frank L. Cooper* 400

Correction to M. Fabry's Note "On the Size of Meteors" . . . 400

"FLASH" Spectrum without an Eclipse, Photography of. *George E. Hale* and *Walter S. Adams* 222

HALLEY'S Comet, Photographs of. *Oliver J. Lee* 237

HAVERFORD, Recent Solar Observations at. *Walter M. Mitchell* . . 75

HOUGH, George Washington. *Henry Crew* 68

LIGHT, Absorption of, in Space, Evidence from Photographic Color-Filters in Regard to. *J. A. Parkhurst* 33

Apparent Dispersion of, in Space. *Paul R. Heyl* 40

Absorption of, in Space. Second Paper. (See also Correction, p. 398.) *J. C. Kapteyn* 284

MAGNETIC Field, Separation of Spectral Lines of Thorium in. *B. E. Moore* 144, 178

Field, Effect of, upon Absorption Spectra of Certain Rare Earths. *William Frederick Schulz* 383

Rotation and Resonance Spectra of Sodium Vapor Photographed with the Concave Grating. *R. W. Wood* and *Felix E. Hackett* 339

MANGANESE, Redetermination of Wave-Lengths of Arc and Spark Lines of. *Clinton Maury Kilby* 243

MERCURY, Determination of Wave-Lengths (International System) for Arc and Spark Spectrum of. *Harold Stiles* 48

METEORS, On the Size of. (See also Errata, p. 400.) *Ch. Fabry* . 318

MOUNT WILSON Photographs of Sun-Spot Spectra, Summary of Results of Study of. *Walter S. Adams* 86

NEBULA, Note on Spectrum of *Andromeda*. *J. Scheiner* 69

Spectrum of *Andromeda*. *E. A. Fath* 167

NEWCOMB, SIMON. *Ormond Stone* 171

β Orionis, The Spectroscopic Binary. *J. S. Plaskett* 26

PRISMS, On Comparison. *H. Konen* 318

RADIAL Velocities, Eight Stars Having Variable. *Edwin B. Frost* and *Oliver J. Lee* 62

RADIATION Exponent of Dry Air. *W. J. Humphreys* 20

RESONANCE and Magnetic Rotation Spectra of Sodium Vapor Photographed with the Concave Grating. *R. W. Wood* and *Felix E. Hackett* 339

REVIEWS:

Rohr, M. von. *Die binocularen Instrumente* (A. C. Lunn) . . . 71

R. Emden. *Gaskugeln: Anwendungen der mechanischen Wärmetheorie* (J. H. Jeans) 72

PAGE

Eugène Néculcéa. *Recherches théorétiques et expérimentales sur la constitution des spectres ultraviolets d'étincelles oscillantes* (Henry Crew) 74

Albrecht, Th. *Formeln und Hilfstafeln für geographische Ortsbestimmung* (Edwin B. Frost) 321

Lohse, O. *Tafeln für numerisches Rechnen mit Maschinen* (Edwin B. Frost) 321

Berberich, A. *Astronomisches Jahresbericht*, X. Band (Frank Schlesinger) 322

SELF-INDUCTION and Capacity, Effect of, on Wave-Lengths of Spark Lines. *Clinton Maury Kilby* 243

SODIUM Vapor, Resonance and Magnetic Rotation Spectra of, Photographed with the Concave Grating. *R. W. Wood* and *Felix E. Hackett* 339

SOLAR Observations at Haverford, Recent. *Walter M. Mitchell* . . 75

SPARK and Arc Spectrum of Mercury, Determination of Wave-Lengths (International System) for. *Harold Stiles* 48

and Arc Lines of Titanium, Manganese, and Vanadium, Redetermination of Wave-Lengths of. Effect of Capacity and Self-Induction on Wave-Lengths of Spark Lines. *Clinton Maury Kilby* 243

SPECTRA, Sun-Spot, Summary of Results of Study of Mount Wilson Photographs of. *Walter S. Adams* 86

of Compounds of Alkaline Earths. *Albert Eagle* 231

of Certain Rare Earths, Effect of Magnetic Field upon Absorption. *William Frederick Schulz* 383

Resonance and Magnetic Rotation, of Sodium Vapor, Photographed with the Concave Grating. *R. W. Wood* and *Felix E. Hackett* 339

SPECTRAL Lines of Thorium in Magnetic Field, Separation of. *B. E. Moore* 144, 178

SPECTROSCOPIC Binary β *Orionis*. *J. S. Plaskett* 26

Binaries. Eight Stars Having Variable Radial Velocities. *Edwin B. Frost* and *Oliver J. Lee* 62

Binaries, Seven. *S. A. Mitchell* 239

Binaries, Two Curiously Similar. *J. S. Plaskett* and *W. E. Harper* 373

SPECTRUM of Calcium, New Lines in. *James Barnes* 14

of Mercury, Determination of Wave-Lengths (International System) for Arc and Spark. *Harold Stiles* 48

of *Andromeda* Nebula, Note on. *J. Scheiner* 69

Arc, of Vanadium in Region λ 5800 to λ 7364. *H. Shaw* . . 127

of the *Andromeda* Nebula. *E. A. Fath* 167

Photography of the "Flash," without an Eclipse. *George E. Hale* and *Walter S. Adams* 222

of Comet 1908 *c* (Morehouse). *H. Rosenberg* 267

PAGE

STARS β, γ, δ, ϵ, ζ, *Ursae Majoris*, On New Members of the System of the. (See also Correction, p. 320.) *Ejnar Hertzsprung* . . 135

SUN-SPOT Spectra, Summary of Results of Study of Mount Wilson Photographs of. *Walter S. Adams* 86

SUN-SPOTS, Water-Vapor in. *Walter M. Mitchell* 44

THORIUM, Separation of Spectral Lines of, in Magnetic Field. *B. E. Moore* 144, 178

TITANIUM, Zeeman Effect for. *Arthur S. King* 1

TITANIUM, Redetermination of Wave-Lengths of Arc and Spark Lines of. *Clinton Maury Kilby* 243

Ursae Majoris, On New Members of the System of the Stars β, γ, δ, ϵ, ζ (See also Correction, p. 320.) *Ejnar Hertzsprung* . . . 135

VANADIUM, Arc Spectrum of, in Region λ 5800 to λ 7364. *H. Shaw* . 127

Redetermination of Wave-Lengths of Arc and Spark Lines of. *Clinton Maury Kilby* 243

VELOCITIES, Eight Stars Having Variable Radial. *Edwin B. Frost* and *Oliver J. Lee* 62

WATER-VAPOR in Sun-Spots. *Walter M. Mitchell* 44

WAVE-LENGTHS (International System), Determination of, for Arc and Spark Spectrum of Mercury. *Harold Stiles* 48

of Arc and Spark Lines of Titanium, Manganese, and Vanadium, Redetermination of. *Clinton Maury Kilby* 243

Published in Cooper's Article in Vol. 29 of this *Journal*, Errors in. *Frank L. Cooper* 400

YOUNG, Charles Augustus. *Edwin B. Frost* 323

ZEEMAN Effect for Titanium. *Arthur S. King* 1

INDEX TO VOLUME XXX

AUTHORS

PAGE

ADAMS, WALTER S. A Summary of the Results of a Study of the Mount Wilson Photographs of Sun-Spot Spectra 86

ADAMS, WALTER S., and GEORGE E. HALE. Photography of the "Flash" Spectrum without an Eclipse 222

BARNES, JAMES. The New Lines in the Spectrum of Calcium . . 14

COOPER, FRANK L. Errors in Wave-Lengths Published in Cooper's Article in Vol. 29 of this *Journal* 400

CREW, HENRY. George Washington Hough 68

Review of: *Recherches théorétiques et expérimentales sur la constitution des spectres ultraviolets d'étincelles oscillantes*, Eugène Néculcéa 74

EAGLE, ALBERT. On the Spectra of Some of the Compounds of Alkaline Earths 231

FABRY, CH. On the Size of Meteors. (See also Errata, p. 400.) . . 318

FATH, E. A. On the Spectrum of the *Andromeda* Nebula . . . 167

FROST, EDWIN B. Review of: *Formeln und Hilfstafeln für geographische Ortsbestimmung*, Th. Albrecht 321

Review of: *Tafeln für numerisches Rechnen mit Maschinen*, O. Lohse 321

Charles Augustus Young 323

FROST, EDWIN B., and OLIVER J. LEE. Eight Stars Having Variable Radial Velocities 62

HACKETT, FELIX E., and R. W. WOOD. Resonance and Magnetic Rotation Spectra of Sodium Vapor Photographed with the Concave Grating 339

HALE, GEORGE E., and WALTER S. ADAMS. Photography of the "Flash" Spectrum without an Eclipse 222

HARPER, W. E., and J. S. PLASKETT. Two Curiously Similar Spectroscopic Binaries 373

HERTZSPRUNG, EJNAR. On New Members of the System of the Stars β, γ, δ, ϵ, ζ, *Ursae Majoris*. (See also Correction, p. 320.) . . 135

HEYL, PAUL R. The Apparent Dispersion of Light in Space . . 40

HUMPHREYS, W. J. On the Radiation Exponent of Dry Air . . 20

JEANS, J. H. Review of: *Gaskugeln: Anwendungen der mechanischen Wärmetheorie*, R. Emden 72

KAPTEYN, J. C. On the Absorption of Light in Space. Second Paper. (See also Correction, p. 398.) 284

Correction to Professor Kapteyn's Article in the November Number 398

PAGE

KILBY, CLINTON MAURY. Redetermination of the Wave-Lengths of the Arc and the Spark Lines of Titanium, Manganese, and Vanadium; the Effect of Capacity and Self-Induction on the Wave-Lengths of the Spark Lines 243

KING, ARTHUR S. The Zeeman Effect for Titanium 1

KONEN, H. On Comparison Prisms 318

LEE, OLIVER J. Photographs of Halley's Comet 237

LEE, OLIVER J., and EDWIN B. FROST. Eight Stars Having Variable Radial Velocities 62

LUNN, A. C. Review of: *Die binocularen Instrumente*, M. von Rohr 71

MITCHELL, S. A. Seven Spectroscopic Binaries. 239

MITCHELL, WALTER M. Water-Vapor in Sun-Spots 44

Recent Solar Observations at Haverford 75

MOORE, B. E. Upon the Separation of the Spectral Lines of Thorium in the Magnetic Field 144, 178

PALISA, J. Celestial Charts by J. Palisa and M. Wolf 70

PARKHURST, J. A. The Evidence from Photographic Color-Filters in Regard to the Absorption of Light in Space 33

PLASKETT, J. S. The Spectroscopic Binary β *Orionis* 26

PLASKETT, J. S., and W. E. HARPER. Two Curiously Similar Spectroscopic Binaries 373

ROSENBERG, H. The Spectrum of Comet 1908 *c* (Morehouse) . . 267

SCHEINER, J. Note on the Spectrum of the *Andromeda* Nebula . . 69

SCHLESINGER, FRANK. Review of: *Astronomisches Jahresbericht*, X. Band, A. Berberich 322

SCHULZ, WILLIAM FREDERICK. Effect of a Magnetic Field upon the Absorption Spectra of Certain Rare Earths 383

SHAW, H. The Arc Spectrum of Vanadium in the Region λ 5800 to λ 7364 127

STILES, HAROLD. A Determination of Wave-Lengths (International System) for the Arc and Spark Spectrum of Mercury 48

STONE, ORMOND. Simon Newcomb 171

WOOD, R. W., and FELIX E. HACKETT. Resonance and Magnetic Rotation Spectra of Sodium Vapor Photographed with the Concave Grating 339

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CONTENTS

CHARLES AUGUSTUS YOUNG - - - - - - - - - - - EDWIN B. FROST 323

THE RESONANCE AND MAGNETIC ROTATION SPECTRA OF SODIUM VAPOR PHOTOGRAPHED WITH THE CONCAVE GRATING - - - - R. W. WOOD AND FELIX E. HACKETT 339

TWO CURIOUSLY SIMILAR SPECTROSCOPIC BINARIES J. S. PLASKETT AND W. E. HARPER 373

THE EFFECT OF A MAGNETIC FIELD UPON THE ABSORPTION SPECTRA OF CERTAIN RARE EARTHS - - - - - - - - - - - - - WILLIAM FREDERICK SCHULZ 383

MINOR CONTRIBUTIONS AND NOTES:
Correction to Professor Kapteyn's Article in the November Number, J. C. KAPTEYN, 398; *Errors in Wave-Lengths Published by Cooper in This Journal*, FRANK L. COOPER, 400; *Errata*, 400.

INDEX - - - - - - - - - - - - -

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Correction to Professor Kapteyn's Article in the November Number, J. C. KAPTEYN, 398; *Errors in Wave-Lengths Published by Cooper in This Journal*, FRANK L. COOPER, 400; *Errata*, 400.

INDEX - - - - - - - - - - - - - - - - - - 401

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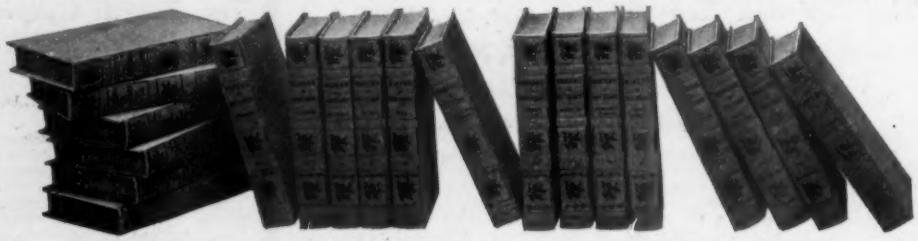

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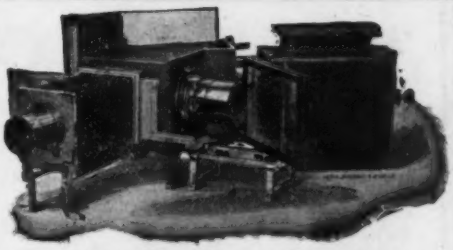

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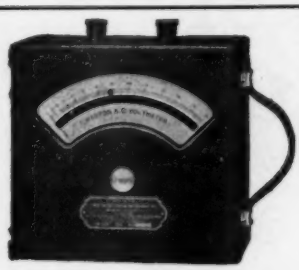

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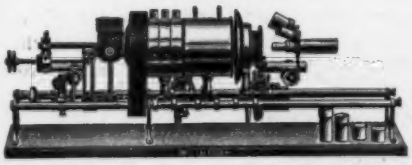

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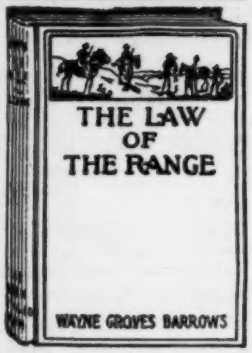

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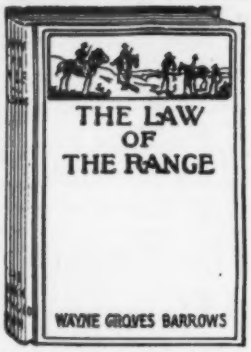

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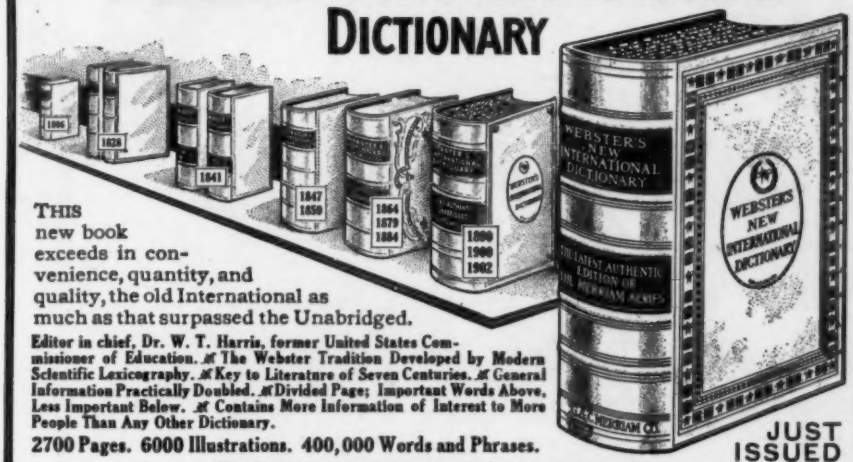

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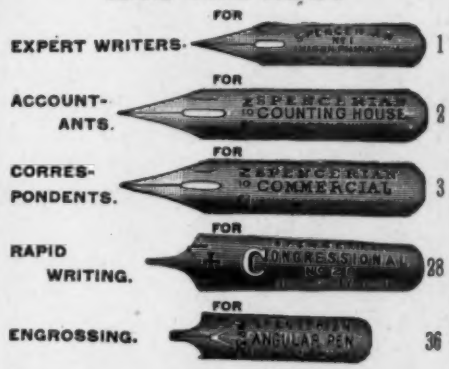

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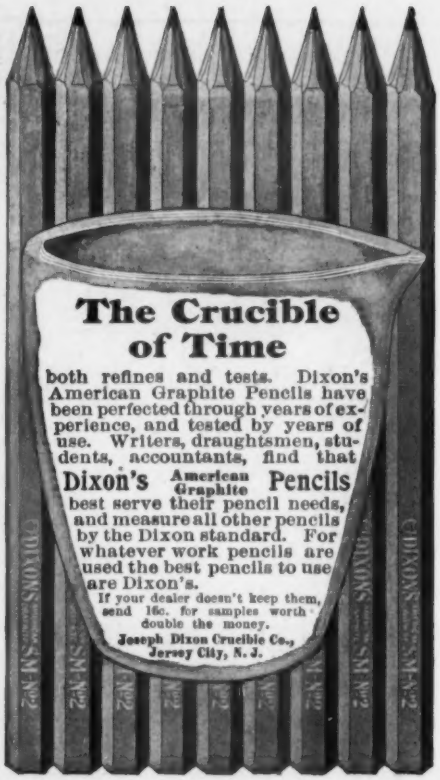
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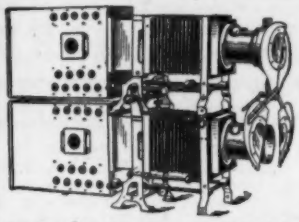

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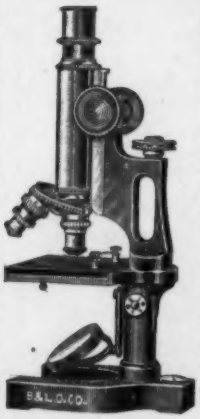

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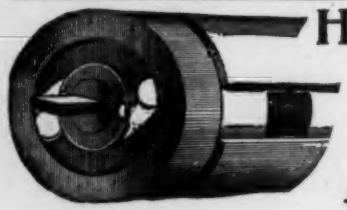

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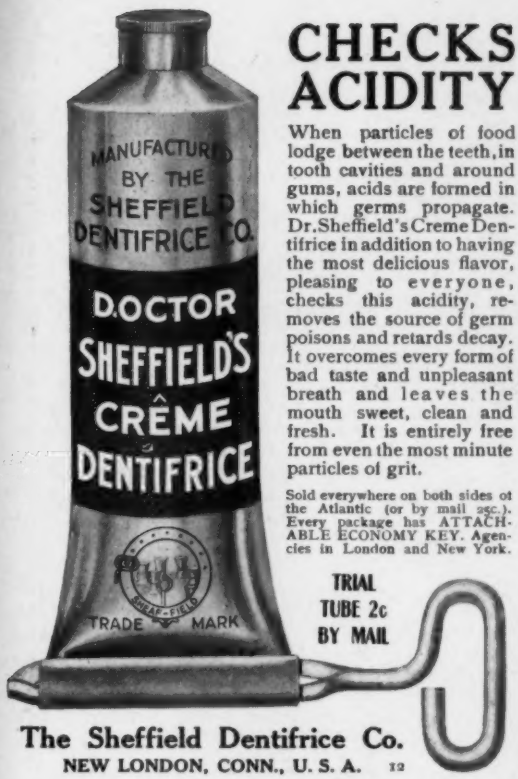

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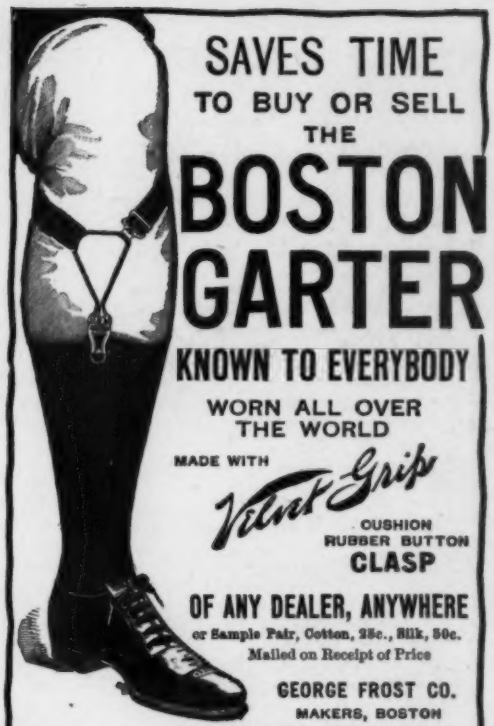

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